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**Guidelines for maintenance
treatment experiments in
California**

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Abstract: <p>This document provides a framework for the Maintenance Section of Caltrans to prepare comprehensive guidelines for the establishment and monitoring of maintenance treatment experiments in the State. Topics covered in the document include:</p> <ul style="list-style-type: none"> • Establishing a study team and assigning responsibilities • Justification for doing an experiment • Developing an experiment specification • Locating, marking out and establishing the site • Construction of the experiment • Monitoring the experiment • Data analysis • Reporting • Data management 				
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PURPOSE OF THIS GUIDELINE

This guideline has been written to assist Caltrans staff with establishment and monitoring of maintenance experiments. Experience has shown that, although numerous such experiments have been built in the past, very little useful information that can be used to make informed decisions about implementing the treatment, technology, procedure or product state-wide results. There are a number of reasons for this including movement of personnel, insufficient or inappropriate data collection and/or loss of interest over time. Considerable time and expense are incurred during the establishment of experiments. Failure to complete an experiment invariably means that it will be repeated by someone else, somewhere else at a later date. The same applies to experiments that although completed, are not coordinated at state level.

This guideline provides direction on the following:

- Establishing a study team and assigning responsibilities
- Justification for doing an experiment
- Developing an experiment specification
- Locating, marking out and establishing the site
- Construction of the experiment
- Monitoring the experiment
- Data analysis
- Reporting
- Data management

By applying the principles discussed in the guideline, the following should be achieved:

- A statistically valid, scientifically correct and defensible answer will be obtained from the experiment within a determined time period
- Every experiment will have a result regardless of the movement of individuals within and out of the organisation
- The findings will be applicable state-wide and useable by individuals outside the study
- Expenses incurred will be justified with a result
- Changes to specifications and practices will be justified
- Individuals will be accountable
- Duplication of effort will be prevented

1. INTRODUCTION

1.1. Background

Caltrans invests millions of dollars each year in pavement maintenance activities. Documented performance of the pavement maintenance practices followed during these activities is important in order for Caltrans to determine which alternatives are most appropriate under particular circumstances. Many factors contribute to this decision including:

- Nature of the problem requiring maintenance
- Existing pavement geometry
- Construction materials
- Location (District)
- Traffic
- Safety
- Environment
- Cost
- Current practice and equipment

In order to establish the most appropriate maintenance practice or to assess the performance and effectiveness of new materials or equipment, experiments are usually constructed and then monitored over a period of time. Provided that an appropriate experimental design is followed, the experiment is monitored regularly and objectively and the data is suitably interpreted, these experiments can contribute significantly to the understanding of pavement maintenance.

However, in many instances, the purpose of the experiment is not clearly defined, accepted monitoring standards are not adhered to, data are not effectively captured and the experiment is not completed with a result on which a decision can be made with regard to state-wide implementation. Alternatively, the originator of the experiment moves and his successor may not be aware or may not be willing to sustain the exercise. Consequently, inconclusive results are often obtained and the new procedure or practice is not adopted. Invariably, the experiment is repeated elsewhere by another individual, often with the same inconclusive result.

The purpose of this document is to provide Caltrans personnel with a guideline for the consistent design, construction and monitoring of experimental sections, capturing and storing data and interpreting and documenting the results. This guideline supplements the “Maintenance Technical Advisory Guide (TAG)” and the “Guide to the Investigation and Remediation of Distress in Flexible Pavements” and uses information from those documents as well as past test section project evaluations located throughout the State of California.

1.2. Key Activities

The design, construction, monitoring and reporting of experimental sections can be divided into a number of key activities, all of which are equally important in ensuring that relevant data are captured and interpreted in such away that an informed decision can be taken on the implementation of the findings of an experiment. These activities include:

- Delegation of responsibility
- Experimental design
- Site selection
- Experiment construction
- Experiment monitoring
- Forensic studies
- Laboratory testing
- Data management
- Reporting

These activities are discussed in more detail in the following chapters.

1.3. Typical Maintenance Activities

Various maintenance activities are performed on highways. Certain activities are preventative in nature in that they are performed before any significant distress has occurred. Others are remedial and are carried out to repair distresses in the pavement. Many routine activities are unlikely to be assessed in research experiments and will not be covered in any detail in this document. Typical activities that will be investigated are listed in Table 1.1. The list is not exhaustive and only provides an example of activities commonly investigated in maintenance treatment experiments. The list does include issues such as drainage,

pavement markings, barriers, water crossings and vegetation control, although investigations can be undertaken on these with a view to improving techniques or assessing new products.

Table 1.1: Typical maintenance activities

Activity	Area affected	Preventative	Remedial
Overlay	Total	✓	✓
Chip seal		✓	✓
Rejuvenator spray		✓	-
Rut fill	Selective	-	✓
Grinding		-	✓
Pothole/punch-out patch		-	✓
Crack seal		-	✓
Joint seal		-	✓

Throughout this document, where appropriate, activities will be referred to as 'total' and 'selective' treatments as detailed in the table.

1.4. Quality Management

Quality management is the coordination of activities to direct and control an organisation with regard to quality. A quality management system is used to guide this process and, in the case of maintenance test sections, refers to Caltrans' structure for managing its processes and activities that transform inputs of resources into a product or service which meet the organization's objectives, namely ensuring consistently designed and tested experiments that provide good quality data that can be used with confidence to develop and implement procedures to improve delivery of infrastructure in California.

Where there is employee turnover, the quality management system and its associated documentation is an aid to continuity of operations. It assists in managing operations based on procedures and not people and helps to prevent unacceptable changes in practice that may occur as a result of changes in personnel.

Quality management encompasses quality control and quality assurance.

1.4.1 Quality Control

Quality Control refers to the activities associated with the creation of project deliverables. It is used to verify that deliverables are of acceptable quality and that they meet the completeness and correctness criteria established in the quality planning process. Quality Control is

conducted continually throughout a project and is the responsibility of team members and the project manager.

1.4.2 Quality Assurance

Quality Assurance does not refer directly to the specific deliverables themselves but rather to the process used to create the deliverables. In general, quality assurance activities focus on the processes used to manage and deliver the solution, and can be performed by a manager, client or a third-party reviewer. For instance, an independent project reviewer might not be able to tell if the content of a specific deliverable is acceptable. However, they should be able to tell if the deliverable seems acceptable based on the process used to create it. They can determine, for instance, whether reviews were performed, whether it was tested adequately, whether the client approved the work, etc.

2. MANAGEMENT AND RESPONSIBILITIES

2.1. Introduction

A team of suitably qualified and experienced personnel is required to manage, establish and evaluate maintenance experiments in close liaison with other units who have responsibility for the road. This team will be accountable for optimising the establishment and evaluation of maintenance treatment experiments and presentation of the highest quality data possible in a format that is useable by other Divisions within Caltrans. The establishment and evaluation of experiments is expensive. Outcomes may result in state-wide changes to current practice and specifications and implementation might be scrutinised by many individuals within the state, as well as nationally and internationally. Roles and responsibilities thus need to be clearly defined and monitored by means of appropriate job descriptions, key-result areas and performance evaluation.

2.2. Staffing

The success of each maintenance test section experiment is directly dependent on the individuals that develop the experiment plan, establish the section, do the evaluations, undertake laboratory tests, and collect, store and analyse the data. The roles and responsibilities of each position in the team thus need to be clearly defined to ensure that relevant positions in the team are accountable for the actions required to effectively deliver each part of the project. It is important to ensure that positions, and job descriptions for those positions, are not created around individuals, but rather to achieve optimal functionality. This will ensure continuity and sustainability of an experiment when staff changes occur - an important issue given the long-term nature of many experiments.

Depending on a particular project, one person may undertake more than one role, but must then accept responsibility for each. Positions will usually form part of a larger job description.

In the event of staff changes, the new position incumbent must assume the responsibilities of the job description, including those linked to maintenance experiments. The job description should be sufficiently comprehensive to ensure that the new incumbent is aware of his/her responsibilities and can accomplish them once adequate training has been carried out.

Typical staffing requirements associated with maintenance experiments include the following. Certain functions could be carried out by the same person, and the positions are unlikely to be full-time:

- Project Director
- Database Manager
- Project Engineer
- Instrumentation Technician
- Evaluators and assistants

The recommended staffing structure is illustrated in Figure 2.1.

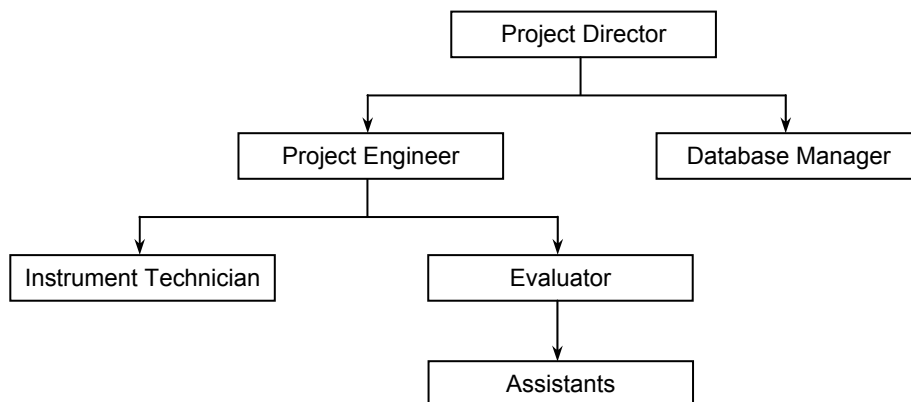


Figure 2.1: Typical staff organisation chart for maintenance experiments

The job descriptions for those positions that are involved with the experiment should be modified to include the additional duties, in line with Caltrans requirements, each with clearly defined roles and responsibilities. Each modification/appointment should be accepted in writing. Thereafter the incumbent should be held accountable for those responsibilities and performance should be rated on achievements related to them.

2.2.1 Project Director

The Project Director has overall responsibility for the experiment. These responsibilities include:

- Liaison with other interested and affected departments within Caltrans
- Overall programme management and accountability
- Securing sustainable funding to complete the study
- Strategy development and review with the “Client”

- Project identification in line with the strategy
- Delegation of authority to the Project Engineer
- Project Experiment Specification approval
- Quality management of outputs
- Industry liaison, coordination feedback and implementation

2.2.2 Project Engineer

The Project Engineer is responsible for ensuring that the Experiment Specification is correctly implemented. He/she will coordinate evaluations and laboratory testing ensuring that appropriate testing is being carried out to meet the objectives of the Experiment Specification. He/she will discuss the need for changes to the Experiment Specification and will be responsible for preparing the first-level report for the test. Involvement in second level analysis and reporting may also be required and will depend on the investigation. This individual reports to the Project Director and his/her job description and key result areas should accommodate the following responsibilities for which he/she should be held accountable and evaluated against:

- Liaison with the Project Director on all aspects pertaining to the experiment(s)
- Liaison with product/technology providers if applicable
- Preparation of Experiment Specifications, project experiment designs and project specifications
- Management of and delegation of authority to the Instrumentation Technician and Evaluators
- Site location
- Layout of the experiment
- Test and control section construction
- Supervision of instrument installation and calibration
- Coordination of associated laboratory testing and control sample storage
- Training and calibration of the evaluators
- Liaison with the Database Manager to ensure that data is useable and in the correct format
- Data validation, first level analysis of results and reporting

2.2.3 Database Manager

The Database Manager should report to the Project Director and should have the following responsibilities for which he/she should be held accountable:

- Maintain a Project File in which all documentation relevant to the experiment is stored
- Provide input to the project Experiment Specification in terms of data formats, database requirements and naming and numbering conventions
- Establish a database architecture to suit the Experiment Specification for each project
- Liaise with the Project Engineer and Laboratory Manager to ensure timeous and accurate capture of data into the database
- Quality checks on all data
- Maintain the database including links to Experiment Specifications and reports, backups and updating of all files and all backups to the latest software versions
- Ensure that all data files are appropriately stored and that raw data is never altered
- Ensure that a backup is made up of the Project Engineers hard drive on completion of each project and stored together with other files from the project
- Facilitate report printing and distribution in suitable formats
- Ensure long-term availability and accessibility of all records in the database
- Establish an archive of all reports prepared on maintenance treatment test sections

2.2.4 Instrumentation Technician

The Instrumentation Technician reports to the Project Engineer and his/her job description and key result areas should accommodate the following responsibilities for which he/she should be held accountable and evaluated against:

- Instrument installation and calibration
- Training of assistants
- Ensuring that a sufficient inventory of instrument components and consumables is maintained and that orders for replacement are timeously placed.

2.2.5 Evaluator

The Evaluator should report to the Project Engineer and should have the following responsibilities for which he/she should be held accountable:

- Evaluation of the experiment(s) according to the requirements of the Experiment Specification
- Submission of data to the database manager
- Assistance to the Project Engineer with first level analysis
- Training of assistants

2.2.6 Evaluator's Assistants

The Evaluators Assistants should report to the Evaluator and assist with instrument test section evaluation, data collection, data processing and other duties as required.

3. PROJECT FUNDAMENTALS

3.1. Introduction

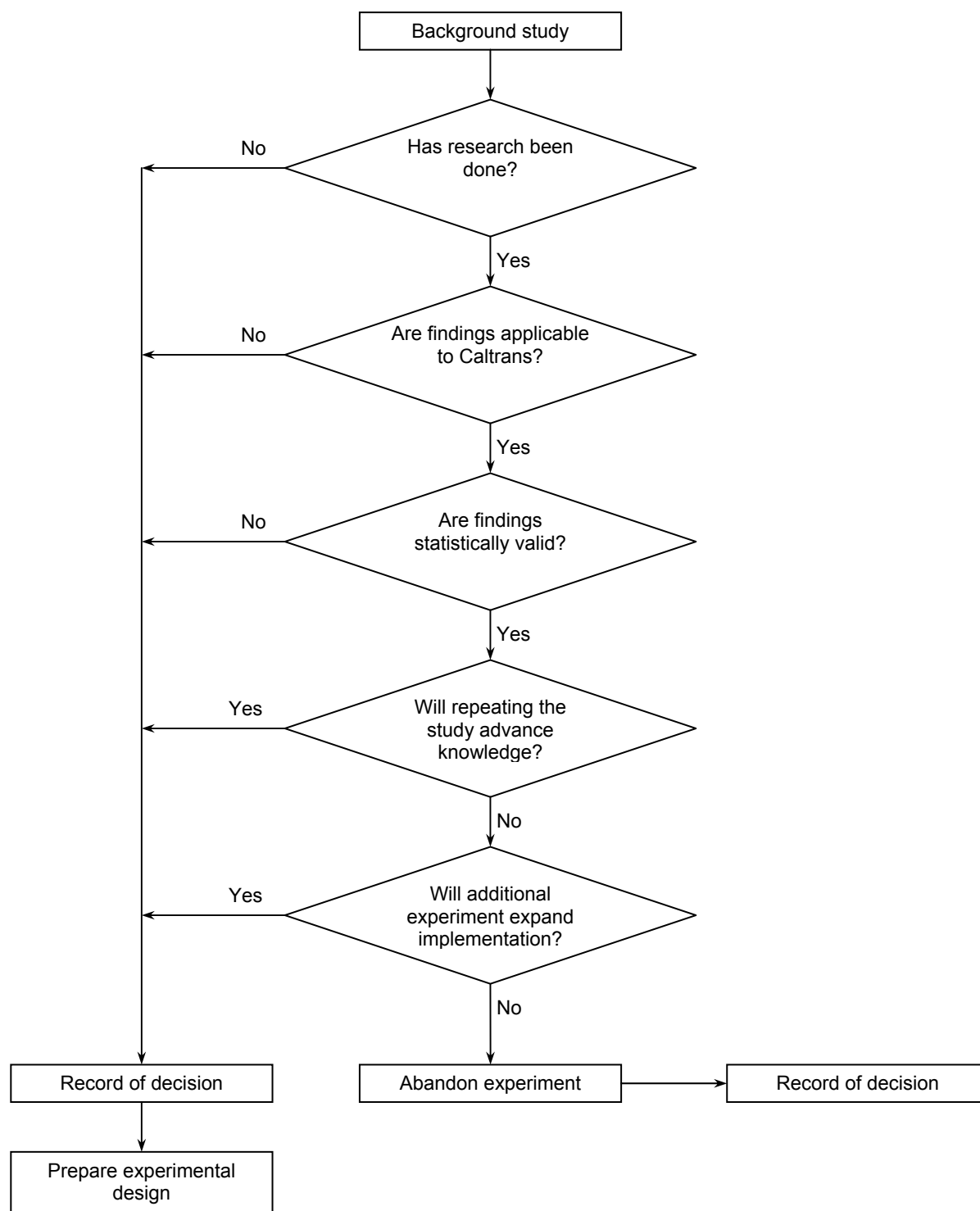
The project fundamentals revolve around the need to do the experiment and the implications of implementing the findings. Experiments are built for a variety of reasons. However, experience has shown that in many instances, the objectives for constructing an experiment are often not fully thought out, insufficient background study is carried out, inappropriate data is collected, monitoring programs and protocols are not adhered to, the results are not written up and the findings are not implemented. Therefore, it is imperative that the reason for initiating the experiment is fully understood and that a comprehensive experimental design is prepared in order to ensure that the objectives are met and, if successful, the procedure being evaluated can be adopted as standard practice, where appropriate, with confidence.

In this chapter, study proposals, background studies and experimental designs are introduced. A flow chart depicting the processes covered in this chapter is provided in Figure 3.1.

3.2. Study Proposal

A study proposal should be prepared as the first step in the process. This proposal should include the following:

- A purpose definition in the form of a problem statement or hypothesis, for example
 - Evaluate the performance of proprietary grids for preventing reflective cracking in overlays
- Reasons and justification for undertaking the study
- Potential benefits of the study
- Details on how the findings would be implemented
- Proposed work plan
- Proposed timetable
- Budget
- Commitment to complete the study

**FIGURE 2.1: Flow chart for background study**

The work plan, timetable and budget should be phased as follows. Each phase can be divided into sub-phases depending on the nature of the study. On large studies, or studies where there is doubt about the need to do a study or understanding about the complexity, approval needs only to be given for one phase on successful completion of the previous one.

- Phase I - Background studies
- Phase II - Detailed study
- Phase III - Analysis and reports
- Phase IV - Implementation

Study proposals should be approved by *Caltrans specific*

A project file should be opened by the proposal motivator and a copy of the approved proposal filed together with any other relevant documentation.

3.3. Background Studies

Before embarking on a detailed research study and construction of experiments that could be both expensive and time consuming, the proponent should carry out a background study to see if similar studies have been carried out elsewhere in the state, in the country or internationally. The study can be done through *Caltrans specific* and the Internet. A detailed literature review, interviews and even some pilot laboratory testing may be required before a decision is made to continue with the study. A brief state-of-the-art report should be prepared on completion of this phase summarizing:

- Overview of why the study is being undertaken and the potential benefits to Caltrans
- Findings of the literature review
 - Details on any similar research that has been carried out
 - The reasons why the practitioners undertook the study
 - How the findings were implemented and what the implications were
- Applicability of the findings to California
- Justification to continue or discontinue the study
- Proposed experimental design

The justification to continue with a study would typically be based on the following (see Figure 3.2):

- No similar work had been carried out elsewhere
- The research was not carried out in a scientific manner such that statistically valid results were obtained
- The findings were not applicable to California (eg different materials or climate)
- The experiment could be considered as a replicate of the previous experiment with data being used to enhance the analysis and reliability of the findings
- The experiment could be considered as another cell in the experimental design covering a specific aspect (eg environmental or traffic) not covered in the previous experiment

A decision to proceed with the experiment should be made by the Project Director after review of the background study report. A record of decision should be documented. All documentation pertinent to this phase of the study, including the record of decision should be added to the Project File. The Database Manager should assume responsibility for the Project File at this time. Copies of the Project File should be kept by the Project Director, Project Engineer and any other individuals involved in the study who will need access to relevant information.

Details on the experiment should be added to the central register of experiments

Caltrans specific

3.4. Experimental Design

The experimental design is a fundamental component of the Experiment Specification, which is discussed in the following chapter.

Sufficient time and effort should always be given to organising the experiment properly to ensure that the right type of data, and enough of it, is available to answer the questions of interest as clearly and efficiently as possible. This process is called experimental design.

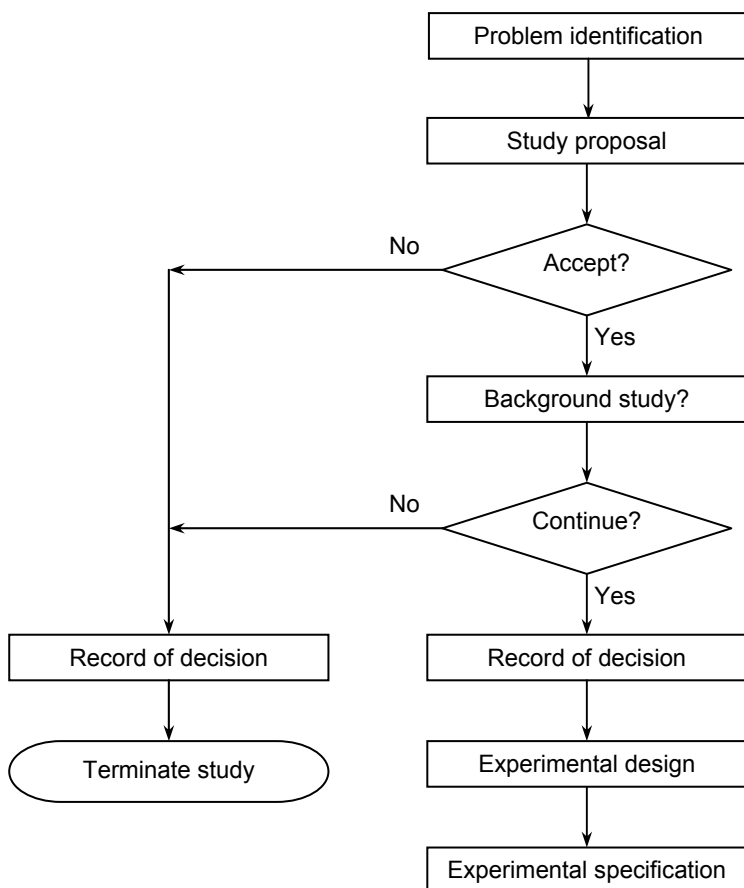


FIGURE 2.2: Flow chart for problem identification

The specific questions that the experiment is intended to answer must be clearly identified together with known or expected sources of variability in the experimental units. One of the main aims of a designed experiment is to reduce the effect of these sources of variability on the answers to questions of interest. That is, the experiment should be designed in order to improve the precision of the answers.

The experimental design is a basic plan of how the study/experiment will be carried out in order to draw a valid conclusion. It should consider all relevant dependant and independent variables and should be sufficiently comprehensive such that a statistically valid conclusion is arrived at. Where appropriate, the experimental design should not be restricted to single experiments and instances, and replicates and variables should be considered to ensure that the results are applicable throughout the state or that the limitations of the procedure, technology or product are fully understood such that it is not implemented where it will not perform satisfactorily.

The following terminology is commonly used in the preparation of experimental designs:

- **Treatments** - In experiments, a treatment is something that researchers 'administer' to experimental units (eg the comparison of different binders to assess which has the least stone loss after opening to traffic). Treatments are usually divided into 'levels', where level is either a categorical variable (eg Binder A, B and C) and/or an amount or magnitude (eg different binder application rates or temperatures).
- **Factor** - A factor of an experiment is a controlled independent variable; a variable whose levels are set by the experimenter. A factor is a general type or category of treatments. Different treatments constitute different levels of a factor (eg, three different binder types are applied at different temperatures. The binders are the experimental units and the application temperatures are the treatments, where three different temperatures constitute three levels of the factor 'type of binder'). Typical factors that may be considered in an experimental design include, but are not limited to:
 - Traffic and type of vehicle
 - Environment (weather, subgrade conditions, water table, etc)
 - Materials
 - Type of pavement
 - Geometry and slope
 - Construction factors (eg binder temperature, compaction equipment)
 - Laboratory test methods that can be correlated with field performance
- **Factorial Design** - is used to evaluate two or more factors simultaneously. The treatments are combinations of levels of the factors. The advantage of factorial designs over one-factor-at-a-time experiments is that they are more efficient and they allow interactions to be detected. Factorial designs are commonly used in road experiments
- **One Way Analysis of Variance** - this allows the comparison of several groups of observations, all of which are independent but possibly with a different mean for each group. A test of great importance is whether or not all the means are equal. The observations all arise from one of several different groups (or have been exposed to one of several different treatments in an experiment). 'One-way' is classified according to the group or treatment.
- **Two Way Analysis of Variance** - is a way of studying the effects of two factors separately (their main effects) and (sometimes) together (their interaction effect).

- **Completely Randomised Design** - the structure of the experiment in a completely randomised design is assumed to be such that the treatments are allocated to the experimental units completely at random
- **Randomised Complete Block Design** - is a design in which the subjects are matched according to a variable which the experimenter wishes to control. The subjects are put into groups (blocks) of the same size as the number of treatments. The members of each block are then randomly assigned to different treatment groups. (eg A researcher is carrying out a study of the effectiveness of four different crack sealants. He/she has 100 cracks on which to assess the sealants and plans to divide them into four treatment groups of 25 cracks each. Using a randomised block design, the cracks are assessed and put into blocks of four according to width; the four widest cracks are the first block, the next four widest are the second block, and so on to the 25th block. The four cracks of each block are then randomly assigned, one to each of the four treatment groups).
- **Main Effect and Interaction Effect** - the main effect is the simple effect of a factor on a dependent variable. It is the effect of the factor alone averaged across the levels of other factors. (eg the results of experiments indicate that two different fog sprays and one chip seal were all effective in extending the life of a pavement surfacing (main effect of fog spray and main effect of chip seal). When fog sprays and chips seals are considered in combination; the two fog sprays might have worked equally well (main effect of fog spray); fog spray A and a later chip seal showed the benefits of both (main effect of fog spray A and main effect of chip seal). However, it might have been found that the use of fog spray B, followed by a later chip seal showed the benefits of both plus a 'bonus', such as significantly extended life of the chip seal, known as an interaction effect (main effect of fog spray B, main effect of chip seal plus an interaction effect).
- **Interaction** - is the variation among the differences between means for different levels of one factor over different levels of the other factor.
- **Randomisation** - is the process by which experimental units (the basic objects upon which the study or experiment is carried out) are allocated to treatments; that is, by a random process and not by any subjective and hence possibly biased approach. The treatments should be allocated to units in such a way that each treatment is equally likely to be applied to each unit. Randomisation is preferred since alternatives may lead to biased results. It tends to produce groups for study that are comparable in unknown as well as known factors likely to influence the outcome, apart from the actual treatment under study. The analysis of variance F tests assume that treatments have been applied randomly.

- **Control** - is a 'do nothing' or a standard treatment to which the performance is compared (eg an experiment to assess the ability of grids to reduce cracking must include a control where no grid is used, built to exactly the same specifications, but excluding the grid).

3.4.1 Types of Experiment

Maintenance treatment experiments can take many forms, including but not limited to:

- Assessing a new treatment/technology (ie does this technology “work”?)
- Comparing one treatment/technology with another (ie which is the “best” treatment?)
- Refining a treatment/technology (ie what is the “best way” to do this treatment/technology?)
- Understanding a treatment/technology (ie “how” does this technology work?)

3.4.2 Factorial Experimental Designs

As mentioned above, factorial experimental designs are often used in maintenance treatment experiments. Care must be taken in deciding on the factors that will be assessed in order to keep the experiment focussed and manageable. It should be remembered that the addition of a factor will result in an exponential increase in the number of cells in the factorial design. For example, an experiment to compare two modified binders with a conventional binder in a chip seal application is proposed. This will require three test sections for a basic experiment without a replicate. If performance is considered to be influenced by traffic, and three different traffic levels are considered, the factorial increases to 3x3 cells or nine sections. If application temperature is also raised as an issue and two different temperatures are considered, the factorial increases to 3x3x2 or 18 sections, and so on. Partial factorial experiments are often used where not all cells are assessed, but instead a selection is tested to identify trends. Unrealistic combinations can also be eliminated to reduce the number of sections.

3.4.3 Replicate Studies

Replicate studies are important in many types of experiment, especially where variables (construction, material variability, weather) can influence performance of the treatment being assessed. The inclusion of replicates will improve the reliability of the findings. Two types of replicate need to be considered:

- Replications within the same test section, typically used to deal with construction, material and/or pavement variability within the test section

- Replications between other regions, materials, pavement types, climates and/or traffic, etc in the state to identify boundaries to implementation

Replications are often overlooked as they are considered to be too expensive. However, experience has shown that if sufficient replicates are not built and assessed, satisfactory implementation is rarely achieved as engineers are resistant to apply new technologies that were not proven under their specific conditions.

3.4.4 Failure Criteria

In any experiment, it is important to establish and understand what the failure criteria for any experiment are and what action needs to be taken when failure occurs.

It should be remembered that most learning with regard to pavement performance and behaviour will be derived from understanding the failure mechanism. It is thus preferable to design experiments in such a way that failure will occur on certain sections. Researchers should be encouraged to adopt this line of thinking and to desist from only designing experiments that do not 'fail'. Care will need to be taken when locating experiments to ensure that road users are not endangered and that maintenance or rehabilitation of the section can be rapidly undertaken without major disruption to traffic.

3.4.5 Experiment Completion

The criteria for deciding when an experiment is completed should also be determined in the experimental design. This will be the point at which sufficient data has been collected such that an informed decision can be made on whether to adopt proceed with implementation or reject the treatment/technology.

3.5. Quality Management

Quality management issues pertaining to the roles and responsibilities described in this Chapter include:

- Preparation of a study proposal
- Completion of a background study to determine whether the research has already been undertaken
- Consideration of an experimental design that will provide sufficient data such that statistically valid conclusions can be drawn with respect to the objectives of the study.

- Approval of the project proposal and continuation of the experiment after completion of the background study by the Project Director
- Documentation of all records of decision
- Opening a central Project File containing all documentation relevant to the study

3.5.1 Documentation Management

At the beginning of any experiment, a Project File should be opened by the Project Proposer. All documentation associated with the study should be kept in this file. Copies of relevant documents should be sent to the project team. Once a proposal has been approved and a project team assembled, the appointed Database Manager should assume responsibility for the Project File.

A register of all project proposals should be maintained, together with a record of decision on whether to proceed or not. This will limit unnecessary duplication of research.

3.5.2 Responsibility

The Project Engineer is responsible for:

- Preparing the project proposal
- Undertaking or delegating someone to undertake the background study
- Writing the background study report

The Project Director is responsible for:

- Approving the proposal
- Approving the background study
- Deciding on whether to proceed with the study

The Database Manager is responsible for:

- Opening and maintaining a Project File
- Distributing copies of relevant documents to the project team

4. EXPERIMENT SPECIFICATION

4.1. Introduction

The Experiment Specification is a comprehensive plan detailing the objectives of the experiment, the experimental design, the control, evaluation procedures and responsible persons. It should be considered a “live” document in that changes during the course of the experiment are often necessitated.

An Experiment Specification must be prepared for every experiment once the decision to proceed with an experiment is made by the Project Director after completion and review of the background study.

In this chapter, the procedure for preparing an experiment specification, the specification content and format and revisions to the specification are discussed. A flow chart depicting the processes covered in this chapter is provided in Figure 4.1.

4.2. Procedure

The preparation of an Experiment Specification involves four main stages:

- Discussion workshop
- Write up
- Review
- Approval

4.2.1 Discussion Workshop

The discussion workshop is held to agree on the test objective and to formulate a framework for the test such that appropriate data will be collected.

The following individuals should participate:

- Project Director
- Project Engineer
- Database Manager

- District Engineer
- Other interested parties, for example, suppliers of products that are being evaluated

The agenda for the workshop should include:

- Objective of the experiment
- Implications of the findings from the background study
- Experimental design to meet the test objective
- Control experiment for comparative purposes
- Experiment location
- Construction requirements
- Instrumentation and equipment required to provide data for envisaged outcome
- Monitoring program
- Monitoring procedure
- Associated laboratory experiments
- Data collection, validation and storage
 - Frequency of data collection
 - Data validation (visual, comparison with previous measurement, within predefined parameters)
 - Data transfer to Database Manager (timing, medium)
- Reports
- Criteria to be met for treatment/technology/procedure/product to be adopted as standard practice
- Implementation plan if successful
- Repairs to road after testing
- Other

The Project Engineer should facilitate the workshop and minute the discussion. These minutes will be used to prepare the Experiment Specification.

4.2.2 Write up

The Project Engineer should write the Experiment Specification based on the agreements reached at the workshop. Although each Experiment Specification will differ according to the objective, a generic content and table of contents should be adhered to, to ensure that all relevant issues are documented. Guidelines for content and table of contents are provided in the following sections.

Responsibilities in preparing the Experiment Specification:

- **Project Director** - responsible for ensuring that the test objectives are aligned with Caltrans policy and procedures
- **Project Engineer** - responsible for preparing the Experiment Specification and liaising with the team members, for preparing the instrumentation requirements, test program, data collection requirements and associated laboratory studies
- **Database Manager** - responsible for providing information on data collected from past experiments with which the proposed experiment may be compared, naming and numbering conventions, formats, data transfer, database design and population and data and report archiving

4.2.3 Review

The draft Experiment Specification should be reviewed by the workshop attendees. The review should focus on technical content and correctness only and fundamental changes differing from what was agreed at the workshop should not be made. The Project Engineer should coordinate the review process and is responsible for setting deadlines for comments, receiving comments, discussing changes with the team members and revising the document.

4.2.4 Approval

The final Experiment Specification should be approved with the following signatures:

- Project Director
- Project Engineer
- Database Manager
- District Engineer

4.3. Experiment Specification Content

The following information should be included in the Experiment Specification. Details on each component are discussed in more detail in later chapters.

- Objective of the test
- Staffing and contact details
- Responsibility and reporting matrix
 - Report preparation

- Report approval
 - Health and safety
 - Environment
 - Data collection
 - Data validation
 - Data submission
- Experimental design, including details on replicates and controls
- Section detail
 - Section number
 - Section details including district, county, road number, lane number and GPS coordinates
 - Test panel position
 - Pavement description
 - Construction, rehabilitation or maintenance interventions required before testing can begin
 - Checklists
- Instrumentation
 - Inventory of instruments
 - Location and/or depth
 - Calibration
 - Measurement specifications
 - Data collection requirements (number and location of points and conditions under which measurements will be recorded)
 - Checklists
- Evaluation program
 - Evaluation detail
 - Protocols/methods/criteria to be followed
 - Failure criteria definition
 - Associated laboratory testing
 - Checklists
- Data collection, validation and storage
 - Start date
 - Frequency of data collection
 - Data validation (visual, comparison with previous measurement, within predefined parameters)
 - Data transfer to Database Manager (timing, medium)
 - Criteria to be met for experiment completion
 - Checklists

- Reports
- General notes

Checklists should be drawn up for each phase of the experiment. These should be used to guide the process and ensure that all parts are completed. They should be signed off by the responsible individuals on completion of a task.

It should be noted that experimental designs should always have an end point. It is thus imperative to include criteria that once met, will result in the termination of the experiment monitoring, data analysis and a recommendation on whether to adopt the treatment, technology, procedure and/or product or not.

4.4. Experiment Specification Format

4.4.1 Table of Contents

The Experiment Specification should be formatted as follows:

- Title Page
- Approval signatures
- Revision Notes
- Table of contents
 - Chapter 1: Objective of the test
 - Chapter 2: Staffing and contact details
 - Chapter 3: Responsibility and reporting matrix
 - Chapter 4: Experimental design
 - Chapter 4: Section detail
 - Chapter 5: Instrumentation
 - Chapter 6: Monitoring program
 - Chapter 7: Data collection, validation and storage
 - Chapter 8: Reports
 - Chapter 9: General notes
 - Appendices: Checklists and forms

4.4.2 Title and Numbering

The title of the Experiment Specification should be a brief descriptor of the project.

Each Experiment Specification prepared should have a unique number to facilitate tracking of updates and changes and for archiving and retrieval purposes. The following numbering system is proposed:

Owner ¹	Document type	Descriptor	Year	Number ²	Version ³	Date ⁴
Dept	Experiment specification	MTS	05	1	1	01/05/05
¹	Responsible Caltrans Department					
²	Sequential number starting at 01 on January 01 each year					
³	Sequential number for each modification to the Experiment Specification					
⁴	Date that the revision is approved					

4.4.3 Examples

Examples of experiment specifications for maintenance treatment experiments are provided in Appendix A.

4.5. Revisions

The Experiment Specification is a live document and might change during the course of an experiment as monitoring progresses. Changes must only be made in order to meet the original objectives of the study and must be agreed to by all individuals involved in preparing the original specification. Examples of changes may include different monitoring intervals, the use of different equipment to measure specific parameters, additional tests, maintenance interventions, etc. Extensions of the experiment may also be justified.

Any changes to the Experiment Specification must be documented in a revision and a new version issued. The new version must be re-approved before implementation. The changes and section numbers in which the changes have been made should be listed on the first page of the revised document.

The Project Engineer is responsible for changes, obtaining approvals, circulation of the revised document and ensuring that the changes are implemented.

4.6. Quality Management

Quality management issues pertaining to the roles and responsibilities described in this Chapter include:

- The preparation of a responsibility matrix
- The preparation of a comprehensive Experiment Specification that defines and allocates all responsibilities required to meet the objectives of the experiment
- Approval of the Experiment Specification by all contributors
- Documenting all changes to the Experiment Specification in revised documents that are re-approved and issued with a revision number and date
- Setting criteria for experiment termination and decision making on whether to adopt the treatment, technology, procedure and/or product as standard Caltrans practice or not.

4.6.1 Documentation Management

The Experiment Specification should be stored in the Project File. New versions of the specification should be circulated to all relevant parties by the Database Manager.

4.6.2 Responsibility

The Project Engineer is responsible for:

- Compiling and revising the Experiment Specification. It is imperative that this responsibility remains with the Project Engineer, unless he/she delegates it to someone else, in order to prevent uncoordinated and unapproved changes to the Experiment Specification that may ultimately influence the meeting of the original objectives.

The Database Manager is responsible for:

- Ensuring that new versions of the Experiment Specification are approved, distributed and added to the Project File

The Project Director retains overall responsibility for approving and implementing the specification.

5. SITE SELECTION

5.1. Introduction

Site selection is critical. The site needs to be representative of roads, traffic and environment where the maintenance treatment might be used if proved successful in the proposed experiment. If feasible, experiments can be combined to facilitate monitoring and comparisons. All experiments should include a control section, typically the standard maintenance treatment that would have been used. When testing treatments such as reinforcing grids, then a section with no grid should be used as a control in addition to a standard grid if one is specified by Caltrans.

In this chapter, site selection procedure, experiment numbering, layout and marking, and instrument installation are discussed. A flow chart depicting the processes covered in this chapter is provided in Figure 5.1.

5.2. Procedure

The identification and selection of experiment sections will depend on the specific criteria and objectives of the study. The following general issues should, however, be considered when selecting sections:

- Sections should be representative of the issue being investigated and results obtained from these sections should be representative of other roads with similar conditions.
- Individual sections within the experiment, including the control, should be similar in terms of alignment, structure and condition.
- The establishment of the section should not pose a safety hazard to road users, or be so positioned that the safety of the persons monitoring the section is jeopardised.
- The road on which the section is being located should not be maintained, rehabilitated or resealed within the planned monitoring period, unless assessment of that intervention is part of the monitoring program and prior warning is given to the Project Engineer.
- Sections should be located as close as possible to traffic counting/weigh-in-motion stations, unless a station is incorporated into the section.

- Sections should be selected such that testing to ‘failure’ of certain sections can be completed and then repaired without significant impacts to the road user.

The procedure involves three main stages:

- Desktop study
- Site visit
- Approval

5.2.1 Desktop Study

The desktop study, undertaken by the Project Engineer in consultation with the District Engineer(s), is done to identify and evaluate all available alternatives that meet the requirements of the Experiment Specification in general and the experimental design in particular, bearing in mind that maintenance treatment experiments are typically incorporated into planned maintenance activities. A shortlist of potential sites, including replicates if applicable, will be prepared as an output. A checklist, based on the requirements of the Experiment Specification, should be completed to ensure that no issues are overlooked. An example of a desktop study checklist is included in Appendix B. Examples of issues to consider include, but are not limited to:

- Can the planned treatments be accommodated in the operation?
- Can the planned maintenance treatment on the selected section be used as a control?
- Is the planned operation long enough to accommodate the experiments?
- Is the alignment uniform?
- Is the planned operation long enough to accommodate replicate sections?
- Are there any potential problems envisaged with monitoring (eg road closures)?
- Are there constraints outside the Experiment Specification that could influence the use of the site (eg safety or environmental issues)?
- Is appropriate construction equipment available?
- Are there appropriately trained personnel to do the treatments?

The selected sites should be ranked according to appropriateness. If replicate sections are required, these should be identified in the ranking.

5.2.2 Site Visit

Following the desktop study, the Project and District Engineers and, if applicable, the supplier(s) of any products that might be evaluated, should visit the selected locations and

identify the most appropriate site(s). Non-destructive (eg profile, falling weight deflectometer) and/or destructive (eg test pit, coring, dynamic cone penetrometer) testing, together with a visual assessment, may be required to characterize the site. Criteria used to select sites could include, but not be limited to:

- Total and selective surface treatments
 - Riding quality (eg International Roughness Index (IRI))
 - Cracking (eg length of crack in mm/km plus crack width or percentage area cracked)
 - Rut depth (eg mm)
 - Bleeding/punching (eg severity (1-5) and extent (percentage area))
- Total surface treatments
 - Age (eg years or period since last treatment)
 - Skid resistance (eg Skid Number (SN))
 - Pavement structure (eg deflection in micron, DCP number, back calculated modulus)
- Selective treatments
 - Potholes

Uniformity of these criteria, and specifically the pavement structure, within the selected site is critical to the success of the experiment in order that analyses and especially comparisons of performance between sections are accurate. The identification of uniform sections within the selected site is thus an important task. Uniformity is relative to the length of the experiment. For short sections (eg <200 m) there should be minimal variation in the key parameter being assessed. For longer sections (eg 1.0 km), some variability is inevitable, but at least the middle 300 m should be uniform and the key parameter should not differ by more than 10 per cent on the remainder of the section.

Issues to consider when selecting uniform sections include, but are limited to:

- Total and selective surface treatments
 - Riding quality - the entire length of the available road should be measured and uniform sections of the required length selected from the data. A variation of not more than 10 per cent is permissible. Sections can be distributed along the length of the available road and need not all be next to each other. If there is a distinctive change over the length of the section, then replicates can be considered, one in the smoother area and one in the rougher area.

- Cracking - the characteristics of the cracking, in terms of the evaluation criteria used, should be consistent along the length of the section.
- Rut depth - the rut depth should not vary by more than +or- 3.0 mm along the length of the section
- Bleeding/punching - the severity and extent of the bleeding and/or punching should be the same throughout the length of the experiment. Replicates can be considered if the severity and/or extent change by more than one rating along the length of the selected site.
- Total surface treatments
 - Age - the entire length of the section should be the same age and should have been constructed at the same time as part of the same contract.
 - Skid resistance - the entire length of the available road should be measured and uniform sections of the required length selected from the data. A variation of not more than 10 per cent is permissible. Sections can be distributed along the length of the available road and need not all be next to each other. If there is a distinctive change over the length of the section, then replicates can be considered, one in the smoother area and one in the rougher area.
 - Pavement structure - sufficient deflection and/or DCP measurements should be taken to ensure that at least five readings are used to identify any one section. Thus a measurement should be taken at least every 20 m. A variation of not more than 10 per cent is permissible. Sections can be distributed along the length of the available road and need not all be next to each other. If there is a distinctive change over the length of the section, then replicates should be considered.

5.2.3 Approval

Once a site, or sites if a factorial experimental design is being followed or replicates are being considered, has been selected, a brief site report should be prepared by the Project Engineer detailing the following:

Site selection process

Criteria used to select individual sections

Exact locations of each section (mileage from a fixed point and GPS coordinates)

Measured parameters for each section

The Experiment Specification should also be updated to incorporate the exact section locations and numbering and a new version issued.

Approval of the location(s) should be signed off by the following individuals:

- Project Director
- Project Engineer
- Database Manager

5.2.4 Safety Considerations

Caltrans specific

5.2.5 Environmental Considerations

Caltrans specific

5.3. Experimental Section Numbering

Each experiment, and section within the experiment if applicable, should be assigned a unique number for management purposes. The issuing of experiment and section numbers should be the responsibility of the Database Manager. The numbers used should correspond to those used in the Experiment Specification and on all subsequent reports.

Caltrans specific

5.4. Experimental Section Layout and Marking

Labelling and marking of the test sections and control should be the responsibility of the Project Engineer. Once selected the test sections should be labelled, marked and instrumented according to the requirements of the Experiment Specification. Suitable signs should be erected at either end of the experiment with experiment details and a contact number or website where Caltrans staff can obtain additional information and notify the Project Engineer of any observations or interventions that may be necessary.

The length of the experiment will be detailed in the Experiment Specification and will vary depending on the treatment being assessed. Typical sections lengths are:

- Total surface - 200 m

- Selective surface - sufficient length to have at least 12 replicates with the same treatment (ie 12 cracks, 12 potholes, 12 joints)

Long test sections are more representative of the road and allow the collection of larger quantities of data. However, they are time consuming to evaluate and variability will need to be accounted for. The length of the test section thus needs to be optimized such that the experiment objectives can be satisfactorily met.

Experimental sections that assess total surface treatments can be divided into two parts - a larger experiment over which riding quality is measured (eg 500 m) and a shorter section (eg 200 m) in the middle where the visual assessment and more precise measurements are taken. Each detail section can be further divided into panels to facilitate evaluation. The control section dimensions should be identical to those of the experiment. An example of a layout typically used for experiments assessing total surface is provided below (Figure 5.2):

- 2 No 20 m panels (A and C) at either end for destructive testing (DCP, density and moisture content, core)
- 1 No 10 m panel (B) in the middle for destructive testing (DCP, density and moisture content, core)
- 10 No 15 m panels (1 - 5 and 6 - 10) for general performance assessment

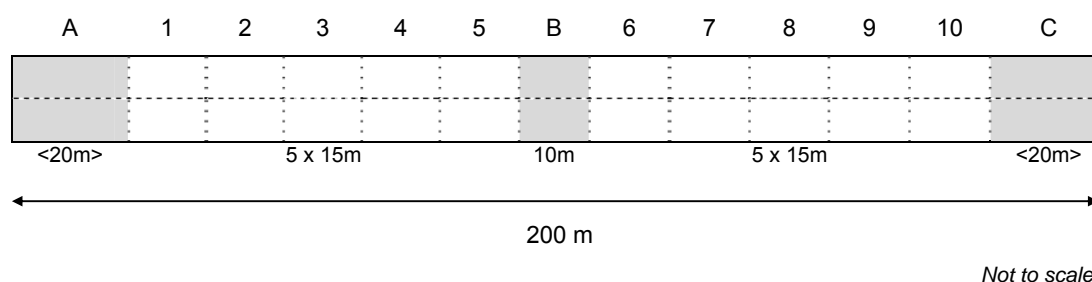


Figure 5.2: Example layout of experimental section (one lane width)

The GPS coordinates of the start of Panel A, centre of Panel B and end of Panel C of each section and the chainage at the beginning and end of each section should be taken and recorded in the database to facilitate location.

Each section should be marked as follows:

- Signboards with the section number should be erected at either end of each section against the fence line/edge of the road reserve. If additional sections are incorporated for riding quality measurements, additional signs should be erected at the start and end point as well.
- Each section should be demarcated and numbered with white road marking paint (Figure 5.2). Locator points for specific measurements (eg deflection (FWD)) should also be painted.

A “map” of each section should be drawn after completion of the demarcation and filed at in the Project File at a central point to facilitate future assessments. An example of an experiment map is provided in Appendix A.

5.5. Instrument Installation

In certain instances, experimental sections may be instrumented in order to collect specific data. Instrumentation requirements will be detailed in the Experiment Specification. Typical instrumentation could include, but is not limited to:

- Temperature or temperature/humidity buttons
- Thermocouples
- Strain gauges
- Crack activity measuring instruments
- Traffic counters and or weigh-in-motion sensors

Instrumentation should be installed and calibrated as prescribed by the manufacturer/supplier, if necessary by trained, experienced and competent technicians.

The control section must be instrumented exactly the same as the experiment.

The Project Engineer must oversee the calibration and installation of the instrumentation.

5.5.1 Reference Standards

Caltrans specific

5.6. Weather Station

Weather data will be an important component of the analysis. If there is no suitable weather station in the vicinity of the experiment, a station comprising at least a thermometer (maximum and minimum) and a rain gauge should be erected as close as possible to the section.

5.7. Checklists

Checklists for site location, layout and marking and instrumentation should be completed and signed off by the Project Engineer and approved by the Project Director. Examples of checklists for the Chapter are provided in Appendix B.

5.8. Quality Management

Quality management issues pertaining to the roles and responsibilities described in this Chapter include:

- Identification of a suitable location for the experiment
- Issuing each section a unique number
- Layout of the sections according to the Experiment Specification
- The drawing of a “map” of the section with all relevant information including instrumentation
- The completion and signing of checklists for each stage

5.8.1 Data Management

Data collected during this phase of the experiment will typically include a “map” of the experiment (treated sections and control), a list of the instrumentation with locations and details of the weather station. Section numbers will need to be recorded in a central experiment register. All documentation generated during the phase of the experiment should be added to the Project File.

5.8.2 Responsibility

The Project Engineer has overall responsibility for:

- Locating the experiment
- Laying out the sections
- Obtaining experiment and section numbers from the Database Manager
- Preparing a “map” of the experiment
- Overseeing the calibration and installation of the instrumentation
- Revising the Experiment Specification
- Completing all checklists

The Database Manager is responsible for:

- Issuing the experiment and section numbers
- Recording the details of the experiment in the experiment register
- Maintaining the Project File

The District Engineer is responsible for:

- Approving the location of the site

The Project Director has overall responsibility for:

- Ensuring that the site meets the objectives of the experiment
- Ensuring that all Caltrans requirements in terms of safety and environment are met
- Approving all checklists

6. EXPERIMENT CONSTRUCTION

6.1. Introduction

The performance of any road is directly related to the quality of construction. It is therefore imperative that the construction process is closely observed in order that later performance can be related back to the construction process. Since maintenance treatments are being evaluated, it is also very important that the road is comprehensively evaluated before any maintenance is undertaken in order to determine the level of success of the treatment.

When undertaking any assessments, observations or measurements, it should always be kept in mind that the data will ultimately be used in an analysis to determine the effectiveness of the technique and/or product being assessed. Careful consideration should thus be given to the manner in which the assessments, observations and measurements are recorded such that quality analysis can be undertaken and valid conclusions drawn.

In this chapter, pre-construction assessment, construction assessment, material sampling and instrument installation are discussed. A flow chart depicting the processes covered in this chapter is provided in Figure 6.1.

6.2. Pre-Construction Assessment

The experiment should be systematically and comprehensively assessed prior to the maintenance treatment. The assessment criteria used should be as detailed in the Experiment Specification and should remain consistent throughout the study. The California Visual Assessment Guide(?) and/or the FHWA Distress Identification Manual for the Long-term Pavement Performance Program should be used together with any additional requirements detailed in the specification. Profile, riding quality and deflection, if specified, should all be measured according to documented procedures.

Typical issues to consider in the pre-construction assessment include, but are not limited to:

- Relevant distresses listed in the Visual Assessment Guide/Distress Identification Manual including, but not limited to:
 - Cracking (fatigue, block, edge, longitudinal, reflection, transverse, corner, durability)

- Potholes and/or existing patching and patch deterioration
- Surface Deformation (rutting, shoving)
- Surface Defects (bleeding, polished aggregate, ravelling, map cracking, scaling, popouts)
- Miscellaneous Distresses (lane-to-shoulder dropoff, lane-to-shoulder separation water bleeding and pumping, blowouts)
- Joint Deficiencies (joint seal damage, spalling, faulting)
- Longitudinal profile/riding quality
- Skid resistance
- Drainage on the road
- Drainage away from the road
- Structure (FWD, DCP)

All observations should be recorded on the Pre-assessment Visual Assessment Form (Appendix C). Any additional notes relevant to the experiment should also be noted.

6.2.1 Reference Standards

Caltrans specific

6.3. Construction Assessment

Every aspect of the construction process, from preparation of the surface through to cleaning up excess materials (eg brooming after chip seal application) can influence later performance of the treatment. The process thus needs to be observed and systematically documented in order that later performance can be linked to the construction process where applicable. Such observation may also form the basis of a motivation to change construction practices or training programs within Caltrans to address any specific problem areas.

Examples of critical areas requiring observation include, but are not limited to:

- Calibration of the spray rate on fog spray and chip seal applications
- Brooming of excess stone after chip seal application
- Repair of distress prior to overlay treatments
- Checking binder temperature
- Checking compaction techniques
- Cleaning process and effectiveness in crack, joint and pothole repairs

6.3.1 Proprietary Products

If a proprietary treatment is being assessed, then the manufacturer or supplier should appoint a Project Engineer to direct the process. They should also provide a step-by-step procedure together with checklists that need to be followed in order to ensure that the experiment is constructed correctly. The procedure must clearly state situations that must be avoided and the consequences if they are not.

The two Project Engineers must oversee the entire construction process and must take responsibility for ensuring that the section is constructed as required. The checklists should be signed off by both Project Engineers on completion of the study as part of the quality management procedure.

6.3.2 Observation

The Caltrans Project Engineer must supervise and systematically document the entire process from site preparation through to opening the road to traffic. If applicable, any deviations from procedures for proprietary products should be noted. On completion, the Project Engineer must be fully satisfied that the test section is representative of the Experiment Specification and that sufficient data have been collected from the construction process to adequately relate later performance to the road prior to treatment and to construction, during the analysis phase. A video of the process from an appropriate vantage point may assist in relating performance to construction at a later date.

Typical issues to consider when observing construction include, but are not limited to:

- Systematic documentation of the process and deviations from the procedure provided
- Binder, aggregate and/or premix characteristics
- Equipment condition
- Calibration procedures
- Surface, crack or pothole preparation
- Compaction
- Establishment, application and demobilization time
- Quality control processes followed
- Uniformity
- Wastage
- Problems encountered and how they were dealt with
- Recommendations to improve the process

All observations should be documented on the Construction Assessment Form (Appendix A). A checklist, relevant to the maintenance treatment (example in Appendix B), should be completed to ensure that all aspects of the construction process have been documented and recorded.

6.3.3 Measurement

A quantitative measure will always be more useful than a subjective observation when analysing data collected from an experiment. Where feasible, any component of the process being assessed that can be measured should be measured with appropriate calibrated equipment and the data recorded, either on an appropriate form, or electronically depending on the parameter and the equipment used.

Typical parameters that can be measured during construction include, but are not limited to:

- Time taken for each component
- Characteristics of the surface before and after treatment:
 - Rut depth
 - Crack length, depth and width
 - Pothole shape and depth
 - Joint width
 - Ride quality
 - Skid resistance
 - Noise
- Binder, premix, sealant, air and surface temperatures
- Aggregate size, shape and quantity applied per unit area
- Binder application rate
- Density after compaction

All measurements should be recorded on the Construction Assessment Form together with the observations discussed in the previous section.

6.3.4 Reference Standards

Caltrans specific

6.4. Material Sampling

Representative samples of all the materials used in the maintenance treatment should be collected at appropriate times throughout the construction procedure. Two types of sample may be collected, namely for:

- Laboratory testing
- Reference purposes

Quantities and replicates will depend on the tests detailed in the Experiment Specification. A sample log should be kept with details on:

- Sample number
- The exact location from where the sample was taken (using X, Y and Z coordinates)
- Name of the person who took the sample
- Time that the sample was taken (actual and in terms of the process)
- Where and under what conditions the sample was stored
- Where the sample was sent to and when

All samples should be appropriately labelled with at least the following:

- Sample number (linked to sample log discussed above)
- Date
- Sample owner
- Destination

Typical samples that might be taken include, but are not limited to:

- Binder
- Aggregate
- Premix
- Crack or joint sealant
- Pothole filler
- Fabric, grid or reinforcing
- Pre-treatment cores
- Post treatment cores

Records of all samples should be noted on the Construction Assessment Form.

6.4.1 Reference Standards

Caltrans specific

6.5. Instrument Installation

If applicable, the type of instrumentation and location will be detailed in the project specification. Instrument installation and calibration should be carried out by a trained technician according to the procedure specified by the manufacturer and overseen by the Project Engineer.

Typical instrumentation may include, but is not limited to:

- Thermocouples
- Temperature and temperature/humidity buttons
- Strain gauges
- Crack activity measuring instruments

Records of the instrument installation, precise location and calibration details should be noted on the Construction Assessment Form.

6.5.1 Reference Standards

Caltrans specific

6.6. Checklists

All relevant issues will be listed on the construction checklist, which must be signed off by the Project Engineer(s) on completion of construction. Examples of the checklists relevant to this chapter are provided in Appendix B.

6.7. Quality Management

Quality management issues pertaining to the roles and responsibilities described in this Chapter include:

- Observing and documenting the entire construction process
- Measuring all relevant parameters at the time and to the requirements specified in the Experiment Specification
- Sampling all relevant materials at the time and to the requirements specified in the Experiment Specification
- Installing and calibrating instrumentation according to the manufactures specifications
- Completing all relevant checklists, forms and labels

6.7.1 Data Management

Considerable data will be collected during experiment construction and may include, but is not limited to:

- Pre-construction assessment
- Construction assessment
- Post-construction assessment
- Material sample details
- Instrumentation details

Data should be recorded on appropriate forms designed to meet the needs of the experiment. Examples of forms are provided in Appendix B. Mandatory information should include:

- Name of evaluator
- Date
- Road number
- County/district
- Section name and number
- Signature of evaluator
- Signature of person performing quality management

All documents should be added to the Project File. In order to facilitate later data analysis, all data from the forms should be captured into a spreadsheet as soon as possible after construction. Timeous capture will allow checks to be made and any missing data to be collected while the construction process is still clear in the Engineers mind. A copy of the spreadsheet, named according to the experiment naming principle described earlier, plus date, should be forwarded to the Database Manager.

6.7.2 Responsibility

The Project Engineer is responsible for:

- Observing and documenting the construction process
- Overseeing the sampling of materials
- Overseeing instrument installation
- Completing all relevant documentation

The Database Manager is responsible for:

- Capturing all relevant data in the database
- Maintaining the Project File

The Project Director is responsible for:

- Deciding whether the construction process is sufficiently satisfactory that the experiment can proceed
- Approving all checklists and other relevant documentation

7. EXPERIMENT MONITORING

7.1. Introduction

Experiment monitoring is the phase during which most of the data that will be used in the analysis is collected. Experience has shown that it is also the phase when studies lose momentum and are even abandoned as new interests are followed and/or staff move onto to other activities, positions or employment. It is thus important to maintain interest in experiments and ensure that the monitoring program is adhered to. Movement of staff should not effect the successful completion of a study.

In this chapter, background information on experiment monitoring is provided, operational issues the monitoring timetable, protocols and criteria are detailed and the visual assessment procedure and measurements and sampling are discussed. A flow chart depicting the processes covered in this chapter is provided in Figure 7.1.

7.2. Background

7.2.1 Attributes Of Distress

The appearance of distress is varied and often extremely complex. The task of describing this is achieved by recording its main characteristics – the so-called attributes of distress. The attributes typically used in the assessment of experiments are the:

- Type
- Degree
- Extent

These attributes are defined below in general terms. Detailed explanations relevant to each type of distress are described in the Visual Assessment Guide (*Caltrans specific*).

Types of Distress - The type of distress evaluated will depend on the purpose of carrying out the assessment - modes assessed on chip seal overlays will differ from those assessed on joint seal experiments. A number of assessment parameters are considered essential for any type of evaluation, while detailed descriptions of particular distress types will be required for specific maintenance treatments. Typical parameters assessed include, but are not limited to:

- Cracking (fatigue, block, edge, longitudinal, reflection, transverse, corner, durability)
- Potholes and/or existing patching and patch deterioration
- Surface deformation (rutting, shoving)
- Surface defects (bleeding, polished aggregate, ravelling, map cracking, scaling, popouts)
- Miscellaneous distresses (lane-to-shoulder dropoff, lane-to-shoulder separation water bleeding and pumping, blowouts)
- Joint deficiencies (joint seal damage, spalling, faulting)

These can be assessed individually or in terms of their interactive effect on the functional performance of the road together with deflection, material properties, road profile, drainage etc. An example of this is the development of potholes, which result in deterioration of overall functionality, particularly riding quality.

Degree - The degree of a particular type of distress is a measure of its severity. Since the degree of distress can vary over the pavement section, the degree to be recorded should, in connection with the extent of occurrence, give the predominant severity of a particular type of distress. The degree is described by a number where:

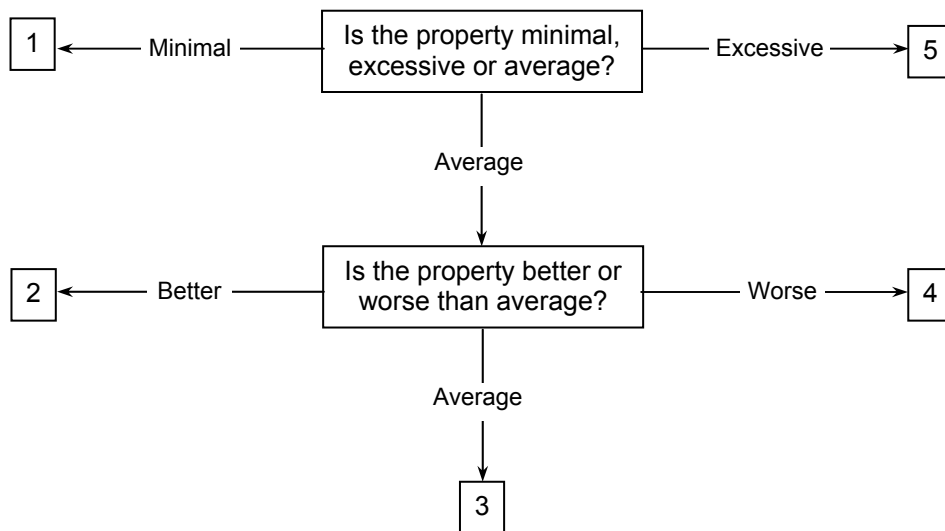
- Degree 1 indicates the first evidence of a particular type of distress (“slight”).
- Degree 3 indicates a warning condition. This would normally indicate that intervention might be required in order to avoid the distress deteriorating to a severe condition.
- Degree 5 indicates the worst degree (“severe”). Urgent attention is required.

The general descriptions of degree of each type of distress are presented in Table 7.1. These descriptions relate to the possible consequences of each type of distress and therefore also to the urgency of maintenance or rehabilitation. Degree 0 is recorded if the defect does not occur. Degree 1 generally indicates that no attention is required; degree 3 indicates that maintenance/improvement might be required in the near future, whereas degree 5 indicates that immediate maintenance/improvement is required. Specific classifications for the various types of distress are documented in the Visual Assessment Guide (*Caltrans specific*), based on these general descriptions.

Table 7.1: General description of degree classification

Degree	Severity	Description
0	None	No distress visible
1	Slight	Distress difficult to discern. Only the first signs of distress are visible.
2	Between slight and warning	
3	Warning	Distress is distinct. Start of secondary defects. (Distress notable with respect to possible consequences. Maintenance might be required in near future)
4	Between warning and severe	
5	Severe	Distress is extreme. Secondary defects are well-developed (high degree of secondary defects) and/or extreme severity of primary defect. (Urgent attention required).

A flow diagram illustrating the use of the five-point classification system is shown in Figure 7.2. The most important categories of degree are 1, 3 and 5. If there is any uncertainty regarding the condition between degrees 1 and 3 or 3 and 5, the defect may be marked as 2 or 4, respectively. This is particularly relevant for research purposes where frequent visual assessments are carried out.

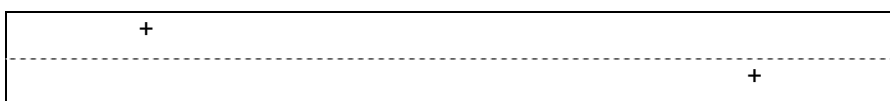
**Figure 7.2: Flow diagram – five point classification system**

Extent - The extent of distress is a measure of how widespread the distress is over the length of the experimental section or panel. The extent is also indicated on a five-point scale in which the length of road affected by the distress is estimated as a percentage. The general description of the extent classifications is given in Table 7.2 and illustrated diagrammatically in Figure 7.3.

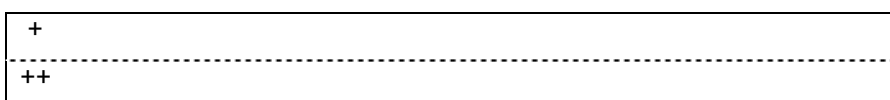
Table 7.2: General description of extent classifications

Extent	Description	Estimate (%)
1	Isolated occurrence, not representative of the section or panel being evaluated.	< 5
2		5 – 20
3	Intermittent occurrence, over most of the section or panel or extensive occurrence over a limited portion of the section.	20 – 60
4		60 – 80
5	Extensive occurrence.	80 - 100

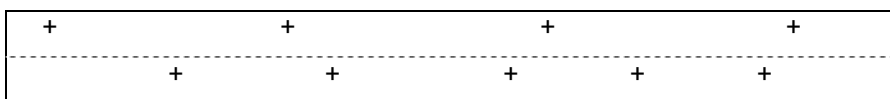
Extent = 1: isolated occurrence



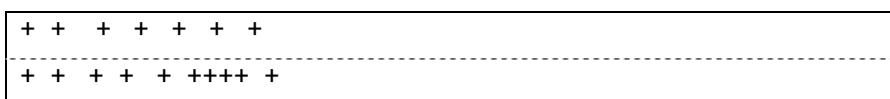
Or



Extent = 3: scattered occurrence over most of length



Or extensive occurrence over a limited portion of the length



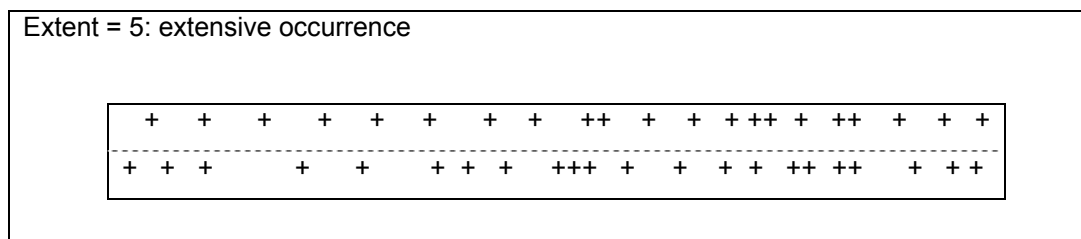


Figure 7.3: Diagrammatical illustration of extent

Experience has shown that even amongst experienced raters, there is a general tendency to overestimate the extent of defects. This tendency increases with severity of the defect.

Examples of the use of Degree and Extent - The following examples illustrate the combined use of degree and extent when assessing potholes:

- If potholing of degree 5 occurs seldom (i.e. extent 1) and potholing of degree 3 occurs extensively (i.e. extent 5), the degree 3/extent 5 potholing is recorded as the predominant indication of the severity of potholing over the specific section. In such a case, the degree 5 potholing will be viewed as an area of localised distress requiring routine attention.
- If potholing of degree 5 and extent 2, and potholing of degree 1 and extent 4 occurs, degree 5/extent 2 is recorded as the average indication of the problem that is most significant in terms of possible action (potholing of degree 1 is not considered significant in terms of possible action).

Depending on the study, the maximum severity possible is often of equal or greater interest than the predominant severity.

7.2.2 Training and Calibration of Evaluators

Numerous individuals may be involved in the evaluation of an experiment or series of experiments over the lifetime of a study and the accuracy, consistency and value of the assessment data will depend largely on the knowledge, experience and commitment of these individuals. To minimise the element of subjectivity and to ensure good knowledge of the assessment procedures, it is essential to train and calibrate all evaluators at regular intervals. The intensity and duration of training will depend on the complexity of the experiment, the requirements as detailed in the Experiment Specification and the experience of the assessors.

An annual training and calibration session should be held even if all the evaluators were trained during previous years. Changes to guidelines and procedures should be presented and problems noted from previous assessments should be discussed and consensus reached on how to deal with them. Evaluators, no matter how experienced, should also be encouraged to regularly calibrate themselves against their colleagues to ensure that interpretations of distress are consistent.

The training and calibration program for assessors should include the following:

- An overview of the objectives of all experiments together with a brief description of the data processing procedures that will be used and potential applications of the final results.
- An overview of the causes of the various types of distress that might be encountered. It is essential that the evaluators understand the causes of the problems in order to make a realistic rating and, if applicable, to list recommendations on potential corrective action.
- An overview of the method of assessment, including descriptions of various types of distress and ratings for each type. The use of colour slides to show examples is recommended. The visual assessment manual and any other relevant guidelines and documentation should be studied by all before the training session.
- An overview of the format of the assessment sheet.
- Practical training, assessing at least 10 road segments, preferably in different conditions exhibiting a full range of defects. The method of rating should be discussed on the first segment which should then be rated jointly with further discussion until agreement and understanding is reached. Each assessor should then evaluate each of the remaining segments individually without discussion with other assessors. The assessment forms should then be compared afterwards and any major discrepancies should be discussed. If necessary, more segments should be assessed and discussed individually until acceptable consistency of rating is achieved.

It is recommended that, during the practical training, those attributes for which estimates of actual depths, lengths, widths and sizes are required should be physically measured to enhance/check the capability of accurate quantitative assessment.

In addition, it is advisable for each Project Engineer to meet with all the assessors within days after the start of the formal assessment to check the initial assessments.

It is essential that evaluators go through this process of training prior to any monitoring exercise. Post assessment calibrations have shown that where assessors were inadequately trained, the assessment has had to be redone.

7.3. Operational Issues

7.3.1 Notifications

Caltrans specific

7.3.2 Equipment

Caltrans specific

7.3.3 Road Closures and Traffic Control

Caltrans specific

7.4. Monitoring Timetable

The monitoring timetable will be detailed in the Experiment Specification. When preparing this timetable, it is important to have a balance between collecting sufficient data and collecting too much. It is also important to identify an expected end point for the experiment, either linked to time (eg exceeds expected design life in years), traffic (eg cumulative vehicles passed or exceeds expected design life in axles) or failure criteria (eg rut depth).

A timetable with long periods between visits could result in missed opportunities to understand when the onset of deterioration started, what caused it and what the ultimate mode of failure was. Interest and momentum could also be lost by the project team. Conversely, a timetable with frequent monitoring visits will be expensive and will lead to significant quantities of often very repetitive data being collected. Interest and momentum could also be lost if the project team consistently has nothing to report.

Monitoring frequency will depend on the type and objectives of the study. At least one and preferably two monitoring visits (ie seasonal) per year should be planned to ensure that sufficient data is collected and that the onset of deterioration is fully understood. More frequent monitoring may be required initially if there is little understanding of potential longer-

term performance (eg new pothole patch products). Issues that need to be considered include, but are not limited to:

- Seasonal factors - If it is likely that performance will change between wet and dry or warm and cool seasons, monitoring should be scheduled for the end of each relevant season.
- Temperature - If diurnal variation in temperature is likely to influence performance, then repeated daily monitoring for short periods (eg a week) should be carried out at predefined intervals such as end of summer and winter or spring and fall.
- Traffic - monitoring can be linked to cumulative traffic that has passed over the section and would thus be linked to information from a traffic counting or weigh-in-motion station
- Time - if there are no specific defining factors, monitoring intervals can be simply linked to time (eg 3, 6 or 12 month intervals). Where possible, it is recommended that time intervals should still be linked to season.

A phased approach can also be followed if there is uncertainty in determining the optimum monitoring frequency. This would entail more regular visits in the initial stages of the experiment until patterns are observed, after which the frequency is reduced. Alternatively, a rapid evaluation (eg drive by) can be undertaken on a frequent basis (eg monthly) to check if deterioration has started with more thorough evaluations being undertaken at six or twelve monthly and even longer intervals.

The Project Engineer will be responsible for ensuring that evaluations are undertaken according to the timetable. Planned evaluations should be diarised and notifications and arrangements should be made timeously to ensure that no delays occur at the chosen time.

7.5. Protocols and Criteria

The protocols and criteria that need to be used as a basis for monitoring will be detailed in the Experiment Specification.

Caltrans specific

7.5.1 Reference Standards

Caltrans specific

7.5.2 Failure Criteria

It is important to establish and understand what the failure criteria for any experiment are and what action needs to be taken when failure occurs.

Examples of failure criteria that can be used in assessing maintenance treatment experiments include, but are not limited to:

- Chip seals and overlays
 - Crack severity and extent
 - Rut depth
 - Stone loss
- Reinforcement materials
 - Reflective cracking
 - Rut depth
- Crack and joint sealants
 - Spalling
 - Separation and/or shrinkage
 - Whip off
- Pothole repair materials
 - Deformation
 - Cracking
 - Separation and/or shrinkage
 - Punch outs

Once ‘failure’ has occurred, the experiment can either be terminated or a maintenance intervention can be carried out and the monitoring continued if a treatment life-cycle is being assessed.

7.5.3 Reference Standards

Caltrans specific

7.6. Visual Assessment

Visual assessments should be carried out on each section or panel according to the criteria detailed in the Experiment Specification and using the protocols described above. Prior to each evaluation, the previous evaluation forms should be reviewed in order that the evaluator

can familiarise him/herself and be able to identify new deterioration and distinguish between deterioration that occurred prior to and after the previous monitoring visit.

A systematic process should be followed such that the entire panel or section is covered and all parts of the evaluation form are completed. The road surface should be viewed from all angles (ie both ends and both sides) to ensure that the angle of sunlight and shadows do not influence the rating.

The evaluation form should be completed in full. If a particular distress is not observed, a zero should be logged to show that it was not overlooked.

The following digital photographs should also be taken during each visit:

- A general view of the road from both ends of the section (eg photographer stands on the outer limit of Panels A and C in the middle of the lane)
- Two photographs of each panel taken from the start and end of each panel in the middle of the lane. A two metre straight edge should be laid across the road at the midway point of the panel as a scale.
- Photographs of any specific distress details should also be taken using the 2.0 m straight edge, or part thereof as a scale. Notes on the photographs should be made in the Notes section on the Visual Assessment Form.

Observations and measurements should be recorded on an appropriate form. Examples of evaluation forms are provided in Appendix C. (*Caltrans specific*)

Output

Completed visual assessment form

7.6.1 Reference Standards

Caltrans specific

7.7. Measurements

Quantitative measures will always be more useful than subjective observations when analysing data collected from an experiment. Where feasible, any component of the process being assessed that can be physically measured should be measured with appropriate

calibrated equipment and the data recorded, either on an appropriate form, or electronically depending on the parameter and the equipment used.

Parameters that need to be measured during the visual assessment will differ depending on the type and objectives of the experiment. Some examples of physical measurements on different experiments are listed in Table 7.3.

Table 7.3: Examples of physical measurements

Measurement	Total surface treatment	Selective treatment
Cracking <ul style="list-style-type: none"> • Fatigue • Block • Longitudinal • Reflection • Transverse • Corner • Durability 	<ul style="list-style-type: none"> ✓ ✓ ✓ ✓ ✓ ✓ ✓ 	<ul style="list-style-type: none"> - - - - - - -
Crack seal <ul style="list-style-type: none"> • Shrinkage 	-	✓
<ul style="list-style-type: none"> • Potholes • Patch deterioration • Patch shrinkage • Patch deformation 	<ul style="list-style-type: none"> ✓ - - - 	<ul style="list-style-type: none"> ✓ ✓ ✓ ✓
Surface Deformation <ul style="list-style-type: none"> • Rutting • Shoving 	<ul style="list-style-type: none"> ✓ ✓ 	<ul style="list-style-type: none"> - -
Surface Defects <ul style="list-style-type: none"> • Bleeding • Ravelling/stone loss • Scaling • Popouts 	<ul style="list-style-type: none"> ✓ ✓ ✓ ✓ 	<ul style="list-style-type: none"> ✓ ✓ - ✓
<ul style="list-style-type: none"> • Miscellaneous Distresses • Blowouts 	✓	✓
Joint Deficiencies <ul style="list-style-type: none"> • Joint seal shrinkage • Faulting 	<ul style="list-style-type: none"> - ✓ 	<ul style="list-style-type: none"> ✓ ✓
Functional <ul style="list-style-type: none"> • Longitudinal profile • Riding quality • Skid resistance • Noise 	<ul style="list-style-type: none"> ✓ ✓ ✓ ✓ 	<ul style="list-style-type: none"> ✓ ✓ ✓ ✓
Structural <ul style="list-style-type: none"> • FWD • DCP • Seismic • GPR 	<ul style="list-style-type: none"> ✓ ✓ ✓ ✓ 	<ul style="list-style-type: none"> - - ✓ -

Output

Completed visual assessment form. Data files for electronically collected data.

7.7.1 Reference Standards

Caltrans specific

7.8. Sampling

The need to remove samples from a section will depend on the type and objectives of the experiment and will be detailed in the Experiment Specification. Typical samples that might be taken include, but are not limited to:

- Cores or blocks
- Loose aggregate
- Crack or joint sealant
- Pothole filler

If required, representative samples should be taken as detailed in the Experiment Specification. A sample log should be kept with details on:

- Sample number
- Date and time that the sample was taken
- The exact location from where the sample was taken (using X, Y and Z coordinates)
- Name of the person who took the sample
- Where and under what conditions the sample was stored
- Where the sample was sent to and when

An example of a sample log is provided in Appendix C.

All samples should be appropriately labelled with at least the following. Examples of sample labels are provided in Appendix C:

- Sample number (linked to sample log discussed above)
- Date
- Sample owner
- Destination

All sample details should also be recorded on the Assessment Form.

Sampling methods are not described in this document. The topic is introduced in Section 7.6 and an overview of sampling procedures is provided in Chapter 8.

Output

Completed sample detail forms

7.8.1 Reference Standards

Caltrans specific

7.9. Forensic Studies

Forensic studies are discussed in Chapter 8.

7.10. Checklists

All relevant issues will be listed on the monitoring checklist, which must be signed off by the Project Engineer(s) on completion of construction. Examples of the checklists relevant to this chapter are provided in Appendix B.

7.11. Quality Management

Quality management issues pertaining to the roles and responsibilities described in this Chapter include:

- Understanding the monitoring requirements of the Experiment Specification
- Training and calibrating evaluators
- Conducting visual assessments and measuring specified parameters at the intervals and to the requirements detailed in the Experiment Specification
- Sampling all relevant materials at the time and to the requirements specified in the Experiment Specification
- Completing all relevant checklists, forms and labels

7.11.1 Quality Control

Depending on who undertakes that assessment, an independent review should be undertaken by the Project Engineer, Project Director or other suitable individual to ensure that evaluations are being carried out according to the requirements of the Experiment Specification and to ensure that the observations are consistent. Individuals undertaking the quality assessments should attend the training and calibrations session together with the other raters.

Quality control assessments should be carried out within one week of the original assessment. Evaluators should not be informed that a follow-up assessment is going to be undertaken. The results of the original and quality control assessments should be statistically compared and the variation should not exceed 15 per cent. It should be noted that, due to the subjective nature of visual assessments, the practitioner undertaking the quality control assessment might not necessarily be correct. If the variation in results exceeds the acceptable limit, the assessment forms should be compared to determine where the discrepancy occurs. If it is derived from the entire assessment, the rater and quality controller should visit the site to understand the discrepancy. If the fault lies with the rater, the assessment will have to be repeated. The rater should either be replaced or retrained.

If a proprietary product is being assessed, the supplier should be invited to participate in assessments.

7.11.2 Data Management

The bulk of the data for the experiment will be collected during the monitoring phase of the experiment. Data should be recorded on appropriate forms designed to meet the needs of the experiment. Examples of forms are provided in Appendix C. Mandatory information should include:

- Name of evaluator
- Date
- Road number
- County/district
- Section name and number
- Signature of evaluator
- Signature of person performing quality management

All documents should be added to the Project File. In order to facilitate later data analysis, all data from the forms should be captured into a spreadsheet as soon as possible after monitoring (ie one week). Timeous capture will allow checks to be made and any missing data to be collected within a short period after the assessment, or while the visit is still clear in the Engineers mind. A copy of the spreadsheet, named according to the experiment naming principle described earlier, plus date, should be forwarded to the Database Manager.

7.11.3 Responsibility

The Project Engineer is responsible for:

- Monitoring the experiment, or delegating an evaluator to do the monitoring. If an evaluator is appointed, the Project Engineer retains overall responsibility for ensuring that that evaluation is carried out at the correct time and according to the requirements of the Experiment Specification.
- Reviewing and approving all evaluations undertaken by the appointed evaluator
- Conducting first level checks to compare the evaluation with previous evaluations to ensure consistency in results
- Ensuring that the forms and other relevant documentation are sent to the Database Manager
- Ensuring that any samples collected reach the laboratory and are tested as per the Experiment Specification

The Database Manager is responsible:

- Capturing the data in the database
- Maintaining the Project File
- The Project Director is responsible for approving all checklists

8. FORENSIC INVESTIGATIONS

8.1. Introduction

Forensic investigations should be considered as a final opportunity to rigorously study the section, the findings of which would contribute significantly to the understanding of how the various treatments performed. Although opening a pit at every experimental section would be desirable (and many would say essential) from a data collection and project completeness point-of-view, a number of factors should be considered before carrying out such an extensive study. These include:

- Value of the data in complementing that already collected - a forensic investigation cannot be justified if no additional contribution to learning or to the database is made above that obtained from routine monitoring of the section
- Cost of the assessment - program funding may not accommodate a forensic investigation at each site
- Disruption to traffic - at least one lane will need to be closed to traffic for the duration of the forensic investigation and reinstatement of the pits
- Impacts on the safety of workers and road users during the closure of the lane
- Potential problems during and after reinstatement resulting from consolidation and seepage of moisture into the pavement layers

The need for a forensic investigation on any section should therefore be carefully weighed against the potential usefulness of the data that can be collected. Essentially, if the root cause of any distress, its extent and its consequences on any section can be satisfactorily determined from the data already collected and that any additional information gathered from coring or a test pit will not significantly add to the understanding of how that pavement is behaving/performing, then a forensic investigation is probably not justified. Conversely, if the section behavior/performance cannot be adequately explained or if pertinent data (e.g. pavement structure) is missing from the database or is questionable, then a forensic investigation may be justified.

In this chapter, the level of detail, test pit location, coring, test pit excavation, sample logistics, test pit logging, in-pit testing and test pit reinstatement are discussed. A flowchart summarising the chapter is provided in Figure 8.1.

8.2. Record of Decision

The decision to undertake a forensic investigation for any experiment should be recorded in the Experiment Specification. Details in the specification should include:

- Reason for undertaking a forensic investigation together with expected benefits of the additional data
- Level of detail selected from seven levels and reason
- Responsibility for the investigation

8.3. Level of Detail

Once a decision is made to proceed with a forensic investigation on a particular experiment, the level of detail required and the need for coring and/or bulk sampling of materials will then need to be determined. Typical levels are:

- | | |
|---------|---|
| Level 1 | 150 or 304 mm core log, with layer descriptions and thicknesses and photographs. This level of forensic investigation would be carried out if disruptions to traffic are a major concern. The core can be removed, described and photographed and then replaced and sealed with considerably less disruption than the opening of a pit. Assessments will probably be limited to bound layers only, as unbound layers tend to disintegrate when extracted. This level does not allow the taking of samples. |
| Level 2 | Test pit log and description with photographs. This level of investigation is carried out to fully describe the pavement structure and distress through the structure. No additional testing is carried out and where possible, materials are reinstated. If the effort is being made to open a test pit, serious consideration should be given to at least obtaining accurate moisture measurements in the different layers (i.e. Level 3 investigation) |
| Level 3 | Level 2 together with gravimetric moisture determinations, density and dynamic cone penetrometer (DCP) measurements through the unbound layers and subgrade (optional). Moisture and density data allows comparison with as built data and can be used to assess the influence of these parameters on performance as well as the influence of distress on the parameters (e.g. moisture ingress through cracks). DCP measurements provide a simple indicator of layer thicknesses and strength, which can be interpreted together |

with the test pit log and moisture and density data and compared with deflection and ground penetrating radar measurements. Although DCP measurements may not be appropriate for the very strong pavement layers in the experiment, they could provide useful information on the condition of the subbase and subgrade.

- Level 4 Level 3 together with cores for assessment of asphalt concrete and Portland cement concrete layers. This level of forensic investigation is required if additional testing of the surface and treated base layers is required.
- Level 5 Level 3 together with bulk samples for grading and Atterberg Limit tests. Level 5 investigations will be carried out if it is suspected that the basic material properties have changed during the life of the pavement, which in turn could have influenced the way the pavement performed. A second round of testing will allow comparison of results with the testing undertaken after construction.
- Level 6 Level 3 together with bulk samples for a full suite of material characterization tests (for replacing missing data), comparison with initial testing or supplemental testing. This level of investigation will be carried out if a more comprehensive comparison with earlier testing is required and/or if additional testing (i.e. tests introduced during the course of the study) are required.
- Level 7 Any level prescribed above together with cores from selected FWD test locations to verify pavement layer thickness.

The level of detail will influence the cost of the forensic investigation and the time that the road is closed to traffic. Guidance on determining the level of detail required is provided in the flow chart in Figure 8.2.

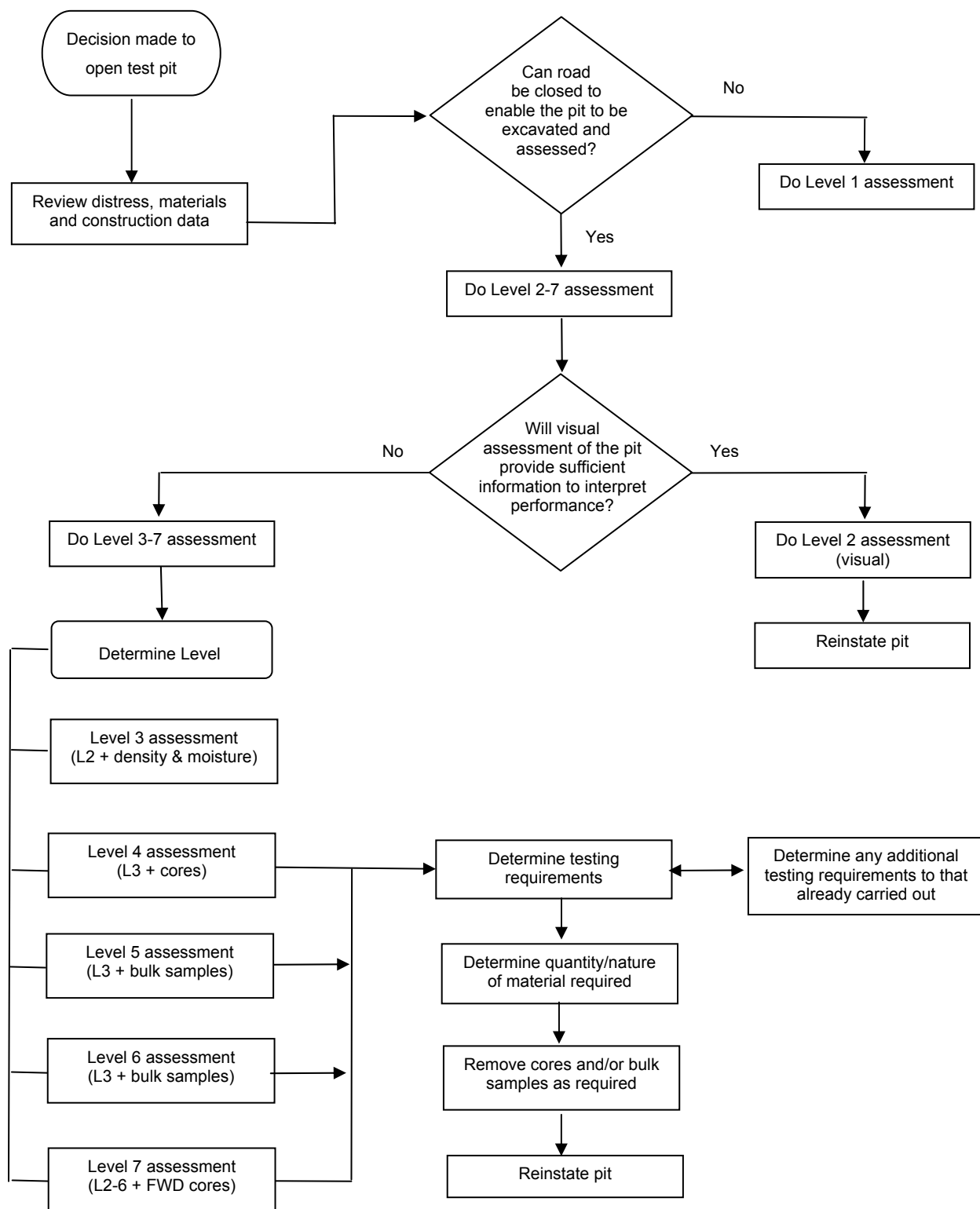


Figure 8.2: Flow chart for determining level of detail of the forensic investigation

8.4. Close-out Monitoring

A complete, final evaluation of the section should be carried out prior to undertaking the forensic study. Data should be recorded on the same Assessment Form used throughout the study.

8.5. Test Pit Location

Forensic investigations should only be carried out once a section is designated as out-of-service so that test pits can be located within the test section. Wherever possible, a “good” and “bad” section within the same experiment should be compared to maximize the understanding of how the pavements behaved. If forensic investigations are required for a specific reason prior to a section being designated as out-of-service, the test pit should be located in an undisturbed area of one of the destructive testing sections before or after the experimental section.

No previous excavation should have taken place at the selected test pit site.

The following procedure for identifying the test pit location should be followed. One test pit per section is recommended unless there is significant variation in performance along the section. In such cases, pits should be located in “good” and “bad” areas of the section for comparison purposes.

- Walk the entire section in both directions and identify potentially suitable locations that are representative of the section.
- Select the most suitable site of those identified. If no clear choice can be made, the center of the section should be selected.
- Mark out the pit extremities from the mid point of the sealed shoulder to the centerline, or at least to a point midway between the inner wheel path and the centerline if there are concerns about working too close to the adjacent trafficked lane. The test pit should be as long as is necessary to meet this requirement, 1.2 m (4 feet) wide and deep enough to expose the top 150 mm (± 6 inches) of the subgrade. Schematics of the test section and test pits are provided in Figure 8.3.
- Depending on the level of detail selected, mark out locations for core holes, density measuring points and dynamic cone penetrometer (DCP) tests. Core hole locations

for verifying pavement layer thicknesses should be marked at each of the FWD positions in the section. Additional core hole locations for closer investigation of distress and joint seals should be marked at an appropriate place on the distress (e.g. across a crack). Consideration should also be given to removing a core from an adjacent area with no distress for comparison purposes and suitable locations should be marked. Examples are provided in Figures 8.4 and 8.5.

- Capture relevant information on a Forensic Investigation Site Report (example Form ? in Appendix C) and prepare a schematic of the test section and test pit location for record purposes (Form ? in Appendix C).
- If a 304 mm (12 inch) core is removed as an alternative to a test pit for the forensic investigation (i.e. Level 1), the drilling site should be located within an area of distress where additional information is required, or if no particular area is identified, across the outer wheel track at the center of the section.

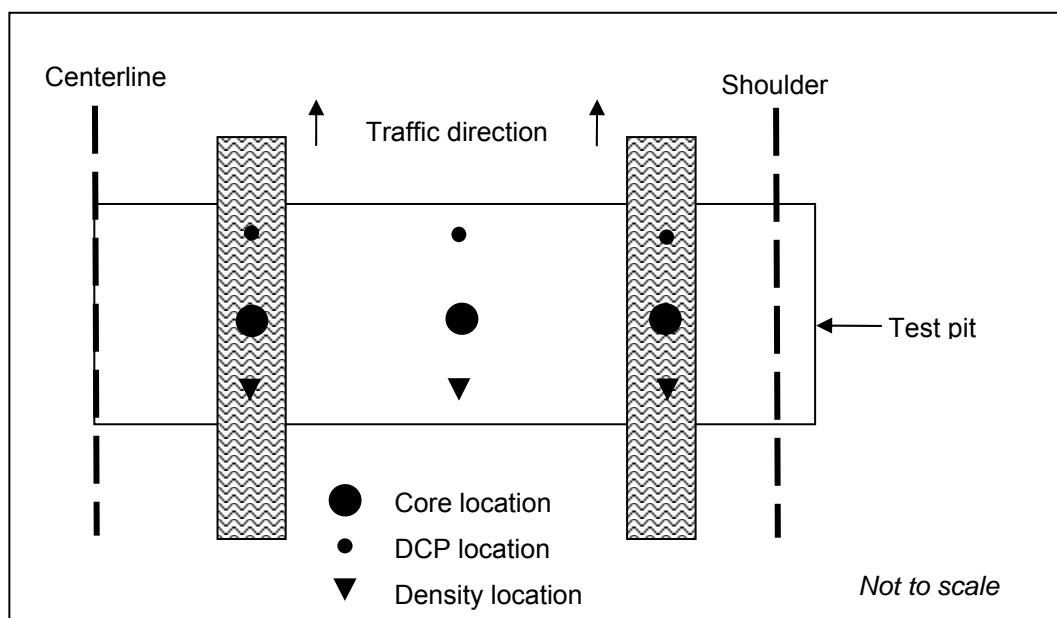


Figure 8.3: Test pit layout

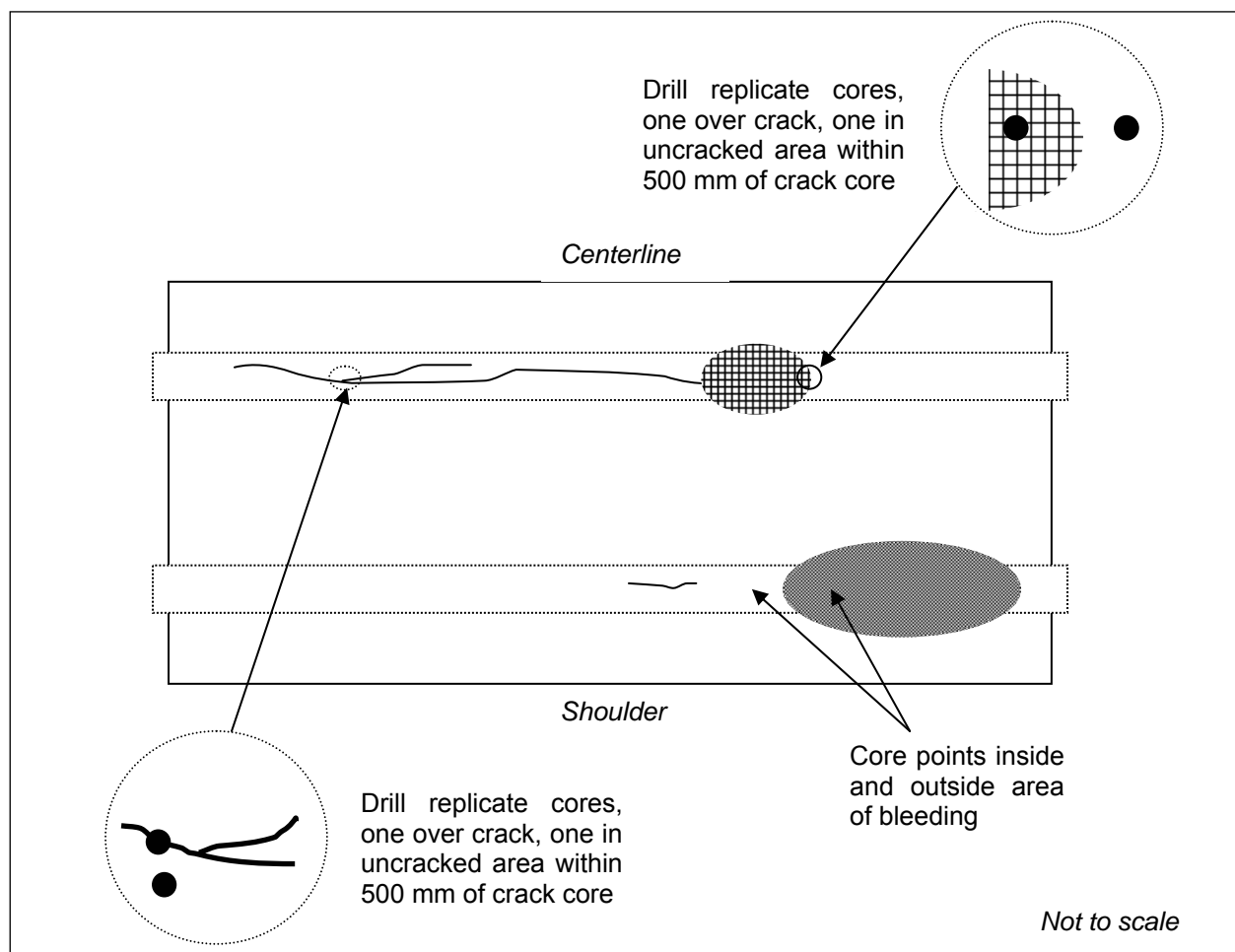


Figure 8.4: Examples of core locations asphalt concrete sections

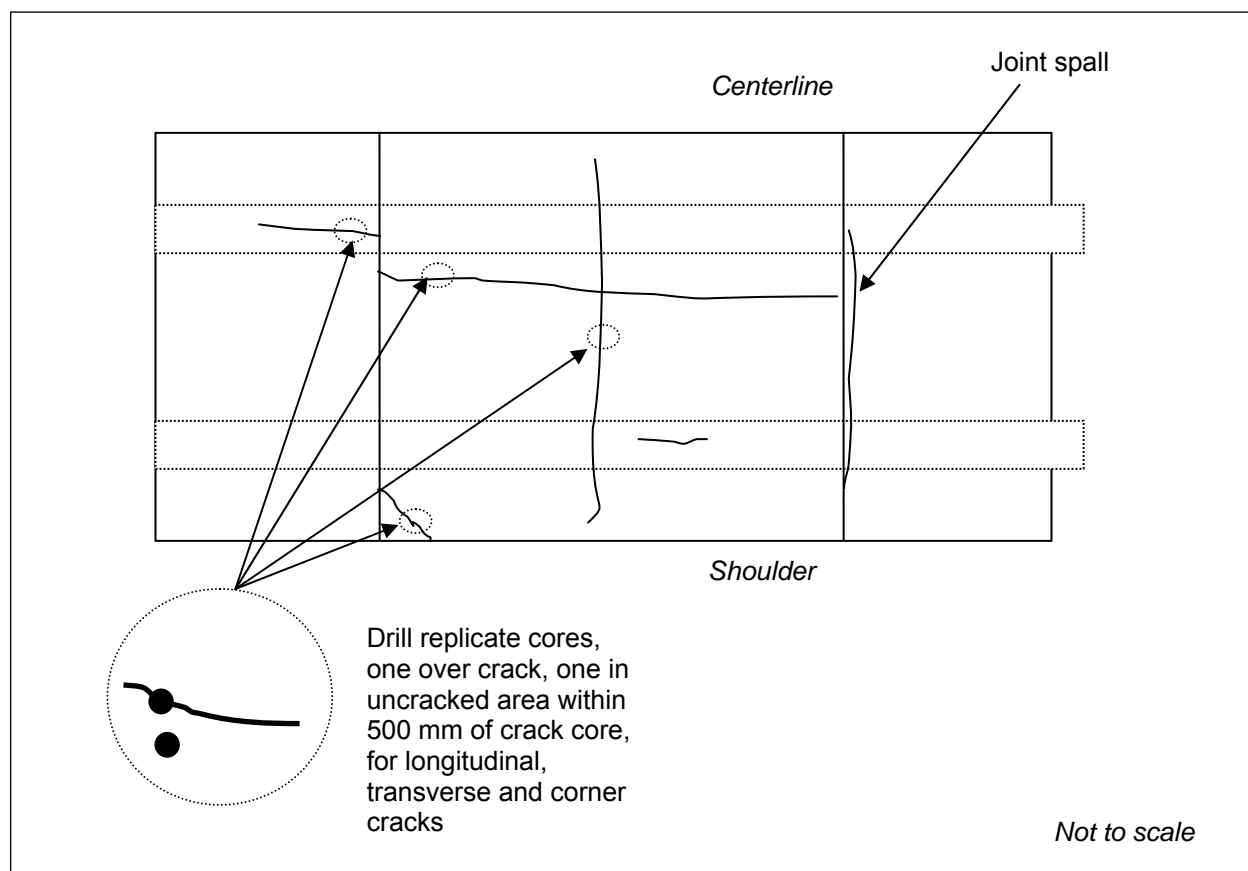


Figure 8.5: Examples of core locations on Portland cement concrete sections

8.6. Coring

All cores should be removed from the marked locations on the section prior to excavation of a test pit (Figures 8.4 and 8.5). If additional material, in the form of cores, is required to supplement material previously sampled from the experiment, these should be removed from the required zones of the section, or from the test pit area, depending on the number of samples that is required. Alternatively, cores can be taken from the slab at a later date.

8.6.1 Reference Standards

The following reference standards are applicable to coring activities at forensic investigations:

- AASHTO R 13 - "Conducting geotechnical subsurface investigations"
- AASHTO T 24 - "Obtaining and testing drilled and sawed beams of concrete"
- AASHTO T 225 - "Diamond core drilling for site investigation"
- AASHTO T 310 - "In-place density and moisture content of soil and aggregate by nuclear methods (shallow depth)"

- ASTM D 2488 - "Description and identification of soils (visual-manual procedure)"
- ASTM D 4083 - "Description of frozen soils (visual-manual procedure)"
- ASTM D 4220 - "Preserving and transporting soil samples"
- ASTM D 5195 - "Test method for density of soil and rock in-place at depths below the surface by nuclear methods"

Motorist and worker safety during coring are of major concern and appropriate measures need to be taken as prescribed in Section 7.3 (Operational Issues).

8.6.2 Equipment

A diamond bit coring drill (mist or air cooled) should be used to remove cores. The size of the core will depend on the testing that is required (e.g. 100 mm (4 inch) or 152 mm (6 inch)). A 304 mm (12 inch) core should be removed for Level 1 forensic investigations. This core will be replaced after the assessment has been completed and photographs have been taken.

Supporting equipment shall include devices for assistance in removal of the cores and patching of the road.

8.6.3 Procedure

Cores shall be taken at an angle of 90° to the surface in such a way as to ensure the recovery of straight, intact smooth -surfaced samples suitable for laboratory testing.

All cores of pavement surfaces shall be marked on the top with an arrow to show the direction of traffic prior to removal of the cores from the pavement. The marking material shall be waterproof so as to remain clearly visible after coring operations.

A separate log shall be prepared for each core hole. The depth of penetration of each coring operation, the average length of the recovered core and the pavement layer thicknesses that can be distinguished, shall be recorded to the nearest 1.0 mm (\pm tenth of an inch). Data sheets for logs are included in Appendix C (Form ?). Remarks shall include type of cooling medium, difficulties encountered in coring, and defects (such as cracks, voids and disintegration) observed in the core.

8.6.4 Core Logging

Cores should be logged using the same criteria as that used for test pits. Test pit logging is described in Section 8.8.

8.7. Test Pit Excavation

This activity involves test pit excavation of the asphalt concrete, Portland cement concrete, treated and untreated base, subbase, and subgrade layers of pavements.

8.7.1 Reference Standards

The following reference standards are applicable to test pit excavation activities at forensic investigations:

- AASHTO R 13 - "Conducting geotechnical subsurface investigations"
- AASHTO R 19 - "Operational guidelines on test pits for evaluating pavement performance"
- AASHTO T 24 - "Obtaining and testing drilled and sawed beams of concrete"
- AASHTO T 310 - "In-place density and moisture content of soil and aggregate by nuclear methods (shallow depth)"
- ASTM D 2488 - "Description and identification of soils (visual-manual procedure)"
- ASTM D 4083 - "Description of frozen soils (visual-manual procedure)"
- ASTM D 4220 - "Preserving and transporting soil samples"
- ASTM D 5195 - "Test method for density of soil and rock in-place at depths below the surface by nuclear methods"

Motorist and worker safety during test pit excavation, sampling, and testing are of major concern and appropriate measures need to be taken as prescribed in Section 7.3 (Operational Issues).

8.7.2 Equipment

The equipment needed includes a pavement saw (mist or air cooled), suitable excavation machine, pneumatic pavement breaker and chisel, and a dump truck. Supporting equipment shall include devices for assistance in removal of pieces of pavement and properly loosening and removing base, subbase and subgrade layers. Hand labor will be required to complete excavation to avoid damaging layers with power equipment and to avoid layer contamination. Equipment for pit reinstatement and patching must also be available. Suitable plastic containers (pots, bags, etc) should be available to seal all samples as soon as they are removed.

8.7.3 Procedure

The pavement shall be sawed to the full depth of the pavement surface and treated layers to the specified overall dimensions and into smaller pieces as necessary for removal. Use of

cooling water during sawing shall be minimized to reduce water contamination of layers. Where possible, air cooled equipment should be used. If saws are not available of sufficient blade diameter to cut through to the base of the treated layers, pneumatic spades and chisels shall be used carefully to minimize damage to underlying untreated layers. If the need for material samples has been identified, then slabs of the pavement surface of appropriate dimensions to satisfy the testing requirements shall be recovered intact for packaging and shipment.

All slabs of pavement surfaces shall be marked on the top with an arrow to show the direction of traffic prior to removal from the pavement. The marking material shall be waterproof so as to remain clearly visible. The asphalt concrete pieces shall be retained in a cloth or plastic bag after removing any water from coring or sawing. The slabs shall be placed with the upper surface down on a wood base prior to insertion in the bag and shall be maintained in that position throughout storage prior to shipping and when packaged for shipping.

After removal of the surface, the base course shall be tested and sampled in accordance with the level of detail identified. The remaining base course layer shall then be carefully removed to expose the subbase and/or subgrade layers, which may also be sampled if required. Excavation shall continue to a depth of 150 mm (± 6 inches) below the top of the subgrade or fill material. If backhoe buckets with teeth are used to excavate untreated layers, care must be exercised during the last few centimeters to avoid disturbing the underlying layer. Hand finishing of excavation of untreated layers is preferred.

Bulk samples of uncontaminated material shall be obtained from those layers in which the need for additional testing has been identified. Care must be exercised to avoid contamination of material from one layer with material from another layer. The size of the sample will depend on the testing that has been identified. Bulk sample quantities required for packaging and shipment shall typically be 150 kg (± 200 lb).

A 5.0 kg (11 pound) moisture sample for laboratory moisture testing shall be sampled from each layer.

8.7.4 Excess Materials

All excess materials shall be temporarily stored for use in re-instating the test pit or disposed of off-site in accordance with local legal requirements.

8.8. Marking, Packaging and Shipping

8.8.1 General Provisions

Field preparation for shipping should be performed in accordance with ASTM D 4220, Group B, for all soil and other unbound materials. Other specific instructions for each type of sample are given below. General requirements for marking and packaging individual samples are as follows:

- Indelible ink pens of black or other suitable color shall be used for marking labels
- Labels and tags shall be of high quality moisture resistant material
- Tins or jars with small portions of bulk samples of materials to be used for laboratory moisture content determination shall be sealed with tape against moisture loss or gain
- Bags for large bulk samples shall be heavy cloth, plastic lined with wire-tie for closing
- Where moisture loss could affect the sample, (eg, stabilized layers, slaking materials) they must be sealed in plastic
- Cores shall be placed in “zip-lock” storage bags and sealed, then wrapped for their entire length with tape (e.g. 50 mm (± 2 inches wide) plastic transparent mailing tape)

8.8.2 Sample Code Number

Each sample (core, block, bulk, moisture) shall be assigned a five-part number that must be recorded on the sample forms for each sample collected. The sample code number will begin with the experiment number, followed by the letter ‘F’ (for Forensic), two letters and one number.

The second letter identifies the sample type in one of the following categories:

- C - core sample
- K - block sample
- B - bulk sample
- M - moisture sample
- P - broken pieces or chunks

The third letter identifies the type of material in the sample in one of the following categories:

- A - asphalt concrete
- P - Portland cement concrete

- T - treated, bound, or stabilized base/subbase
- G - untreated, unbound granular base/subbase
- S - subgrade soil or fill material

Numbers are issued consecutively for samples starting from the shoulder and moving toward the centerline.

If cores of the pavement surface layer and treated base/subbase layer are extracted as one piece, no attempt should be made in the field to separate the cores into separate layers. The core should be labeled separately, packaged and prepared for shipment. Examples are cores of AC layer over stabilized base, AC layer over PCC layer, PCC layer over AC treated layer, PCC layer over stabilized/treated layer including econcrete and cement treated base or subbase.

8.8.3 Labels and Tags

Each sample shall be labeled before being packed and each package shall then be labeled after sealing. All labels shall be secured to the sample, containers and packages in such a manner as to prevent them becoming detached during shipment, handling and storage. As a minimum the following information should be included on tags and labels:

- Experiment and section identification number
- Sample type (e.g. AC core, Bulk sample of AC base, etc)
- Core/sample location (as marked on sample layout plans)
- Sample number
- Sample date

8.8.4 Packaging

Instructions for combining the samples for shipment are as follows:

- All samples of like material (e.g. asphalt concrete surface and binder, cement treated base/subbase/subgrade) shall be placed in separate boxes or separate compartments of one box
- Each sample shall have a label or tag attached that clearly identifies the material prior to testing
- Each core shall be surrounded with “bubble-wrap” or other acceptable cushioning material on all sides within the shipping box. Tape which is used to secure the “bubble-wrap” should not touch the surface of the core

- Block samples of treated materials shall be sealed with wax on all sides, packaged in boxes with cushioning such as “bubble-wrap” or other acceptable material for shipment to the testing laboratory
- Bulk samples shall be marked with two labels or tags. One shall be placed inside the bag and one attached to the outside. A small bag or jar sample for moisture testing of each bulk sample shall be placed inside the bulk sample bag. Pieces from treated layers of coring operations not suitable for testing as cores shall be retained and packaged for shipment as bulk samples
- All shipping boxes shall be wood of suitable grade and construction to withstand shipping and subsequent moving without breakage of the box or damaging of samples
- All boxes shall be adequately secured by nails or screws prior to shipping
- Copies of the Project Site Report (Form ?, in Appendix C) and Material Inventory (Form in Appendix C) shall be included with each shipment

8.8.5 Shipping

All samples shall be shipped to the designated laboratory or storage center within five days of sampling by ground transportation. Each box shall be labeled as described in the previous section. The boxes shall also be labeled “Handle with Care” or similar wording as specified by the transporting organization to insure careful handling and protection from freezing and overheating.

If required, each shipment should be insured for an amount to cover at least twice the cost of the fieldwork performed to obtain the samples.

8.9. Test Pit Logging

Test pit logging (or core logging if a test pit cannot be excavated) is the visual assessment component of the forensic investigation. Although guidelines can be prepared for undertaking this assessment, every assessment will be different depending on the distress that has developed over time, its causes and related consequences. Therefore, each pit or core will have to be closely examined, measured, logged and photographed in a systematic manner and all observations carefully noted to ensure that data are useful for subsequent interpretation and analysis. It must be remembered at all times that the purpose of a forensic investigation is not only to establish the cause of distress and or failure (ie a post mortem investigation), but also to understand how the pavement behaved and to allow comparison

with other similar pavements. This information needs to be presented in such a way that researchers can make use of the data in later studies.

8.9.1 Reference Standards

The following reference standards are applicable to the logging of test pits and large diameter cores at forensic investigations:

- AASHTO R 13 - “Conducting geotechnical subsurface investigations”
- AASHTO T 310 - “In-place density and moisture content of soil and aggregate by nuclear methods (shallow depth)”
- ASTM D 2488 - “Description and identification of soils (visual-manual procedure)”
- ASTM D 4083 - “Description of frozen soils (visual-manual procedure)”
- ASTM D 5195 - “Test method for density of soil and rock in-place at depths below the surface by nuclear methods”

8.9.2 Logging Procedure

Timing

Logging of test pits shall be started within 15 minutes after completion of excavation, before the moisture content of the face of the test changes significantly. Logging of large diameter cores shall begin within 15 minutes of it being removed from the pavement.

Assessment Zones

Layer thicknesses should be measured in each wheel path and the center point between the wheel paths on the transverse faces of the pit and at two positions (approximate thirds) of the longitudinal faces of the pit, for a total of ten measurements. If the study is being conducted on a core, layer thicknesses should be taken at the thickest and thinnest points and these positions noted in respect to the orientation of the core.

Logging should be carried out on the “front” face of the test pit relevant to traffic direction (Figure 8.6). If a core is being assessed, the entire core should be checked. In order to simplify the assessment and later interpretation, the test pit face can be assessed in the following zones for each layer (Figure 8.7):

- Zone 1: Edge of test pit (shoulder) to outside edge of outer wheel path
- Zone 2: Outer wheel path
- Zone 3: Inside edge of outer wheel path to inside edge of inner wheel path
- Zone 4: Inner wheel path

- Zone 5: Outside edge of inner wheel path to edge of test pit (centerline)

If required, each zone can be further subdivided into 9 sub-zones in the form of a grid to simplify the assessment procedure and provide more detail in the interpretation.

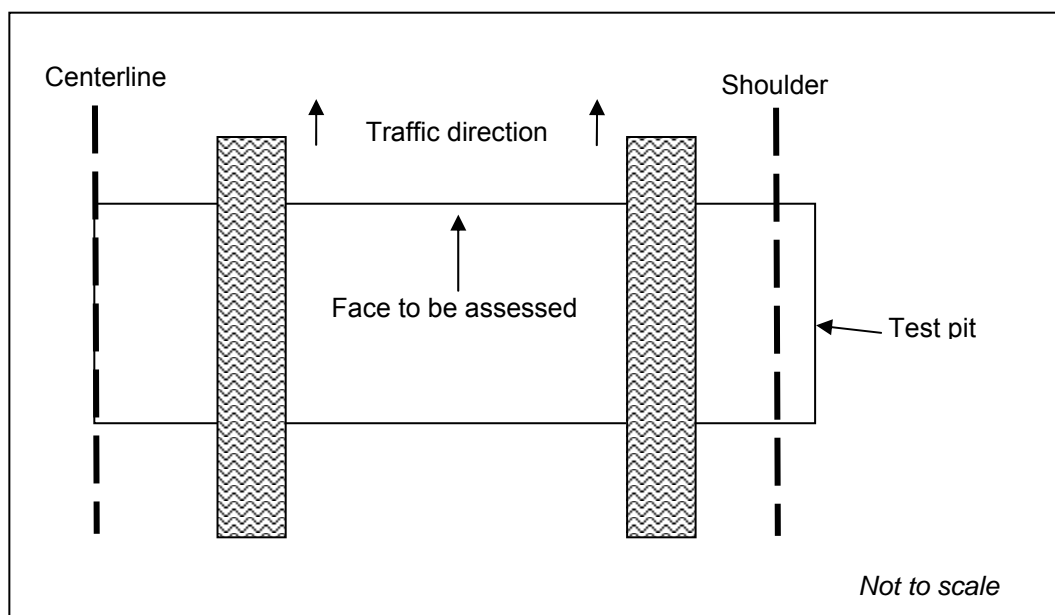


Figure 8.6: Test pit face to be logged

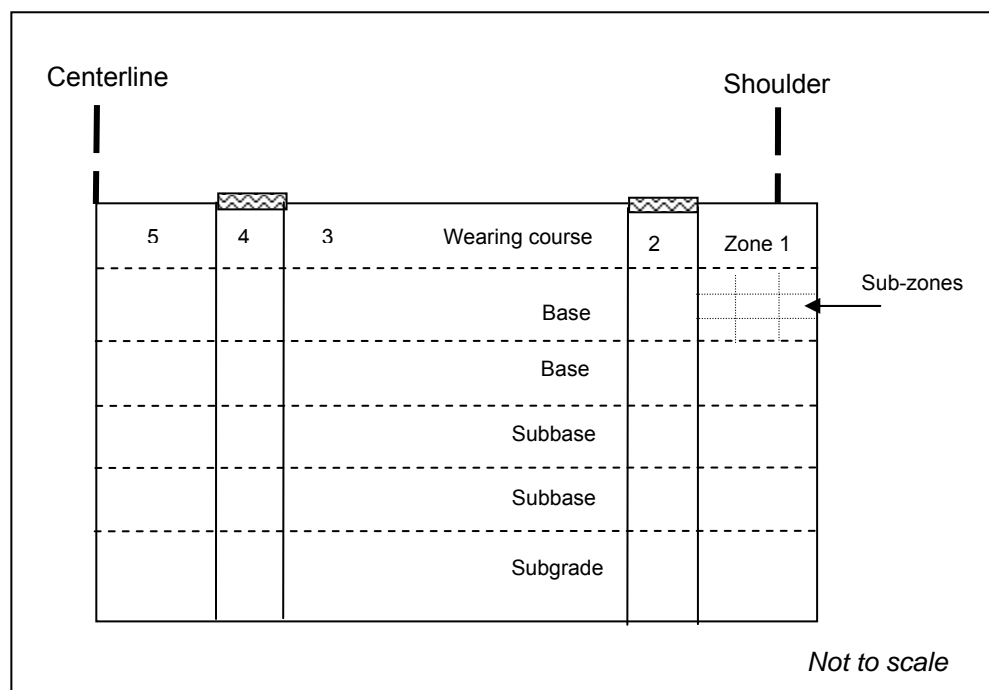


Figure 8.7: Zoning of the test pit

Profile Measurement

The profile of each layer interface should be measured from a stringline. Nails should be driven into each layer interface at either end of the test pit on the selected face. A string should then be tied to the nails and pulled tight and level (no sag) to provide a reference line for measurements. Measurements, to the nearest 1.0 mm, should be taken from the stringline at 100 mm intervals starting from the shoulder side of the pit and working towards the centerline. The maximum offset should also be recorded. The layer profiles and measurements should be recorded on the test pit sketch form (Form ? in Appendix C). Deviations from the norm, pavement design or as built records (eg thicker or thinner layers) should be noted.

Procedure

Within 15 minutes of completion of the entire excavation, the wall of the pit should be scraped with a spade and the pavement profile systematically described and measured. The assessment should be recorded and checked on test pit assessment forms (Forms ? and ? in Appendix C). The record shall include:

- The thickness of each layer to the nearest 1.0 mm ($\pm 1/10$ of an inch). Deviations in thickness from the experimental design should be noted together with an interpretation of what influence this deviation has had on the overall performance of the section.
- The description of each layer, in accordance with the layer designations provided on the preliminary data sheets. A summary of pertinent characteristics is provided in Tables 8.1, 8.3 and 8.5. These characteristics are assessed in terms of a number of criteria. It should be noted that these criteria should be used as a guide only and that the assessment should not be limited to them.
 - *Severity*: where applicable, rated on a scale of 1 (low), 2 (moderate) or 3 (high). Severity descriptors are provided in Tables 8.2, 8.4 and 8.6.
 - *Extent*: describes the percentage area, number of and/or length of the attribute being assessed. Extent descriptors are listed in Tables 8.2, 8.4 and 8.6.
 - *Start*: where applicable, the start point of the defect (e.g. surface or 25 mm below subbase/base interface in Zone 1)
 - *End*: where applicable, the terminal point of the defect
 - *Layers and zones affected*: indicates which layers and zones are influenced by the attribute being assessed, listed in order from start of the distress/attribute to its terminal point

- *Description:* describes the pertinent aspects of the parameter being assessed.
- *Implications:* where applicable, lists the implications and consequences of the distress/attribute (e.g. vertical crack provides a path for the ingress of water and the egress of fines) and links to other distress/attributes.
- Sample numbers and number of bags per sample
- In-pit test numbers

Layers that have been stabilized with cement or lime should be sprayed with a phenolphthalein solution to determine whether any carbonation of the layer has occurred. Those areas of stabilized materials that do not react with the phenolphthalein solution (i.e. turn a dark red color) should also be sprayed with a dilute hydrochloric acid solution and the degree of any reaction (fizzing) recorded. If possible, similar material that has not been stabilized should also be checked for the acid reaction and whether the reaction is weaker or the same as the stabilized layer. This will indicate whether calcium carbonate occurs naturally in the material. Special precautions for handling phenolphthalein and hydrochloric acid should be taken and suitable protective clothing and equipment should be worn when handling the chemicals.

The condition and shapes of the layer interfaces should be examined to determine where rutting and other distress originates. Deep ruts at the surface not reflected at the base/subbase interface indicate that the rutting has taken place in the base course or asphalt concrete surfacing. Where the surface rut is mirrored at the base/subbase interface or the subbase/subgrade interface, the surface rutting is a consequence of compaction or shear at a depth below the interface. Shearing/movement within layers in the form of shiny shear planes (slickensides) can sometimes be observed in specific layers indicating problems within that layer.

Other behavior and its implications such as material degradation or segregation, intrusion of subgrade fines into the subbase and/or base, erosion of the surface of the base layer due to pumping, and drainage deficiencies should also be noted and described. Degradation of the material as a result of frost action can be observed in areas where ground freezing occurs beneath the pavement. If the test pit is deeper than the normal frost depth, visual observations of the material above and below the frost line will reveal to what depth degradation has progressed. Other distress phenomena that should be sought and noted in the cut face of the surface layer include tensile crack formation at the bottom of asphalt concrete layers, D-cracking in Portland cement concrete layers and shrinkage cracking or heaving of swelling subgrade soils.

An indication of drainage deficiencies in any layer can often be obtained by observing the flow rate from the layer into the pit. In “boxed” construction, where the base and subgrade are not free to drain laterally, drainage deficiencies often go undetected prior to the development of surface distress. The apparent effectiveness of in-pavement drainage features on those sites equipped with them should be assessed for functionality and clogging. If necessary, functional evaluation tests (water injection) should be carried out.

Examples of test pit observations are provided in Figures 8.1 to 8.4 (*These photographs need to be included as an illustration to the discussion*).

Good quality digital photographs of the test pit profile shall be taken immediately after excavation. The photographs shall be taken at and keyed to the locations described on the test pit log (Form ? in Appendix C). The photographs shall be taken to provide a total view of the test pit and close-up views of the pavement profiles. All photos should be taken with the sun behind the photographer whenever possible to avoid shadows. Close up pictures should be taken of distress and associated consequences (e.g. mottling around cracks indicating water saturation) within the pavement structure and cross referenced to the assessment form. The photographs should be stored on a CD, marked and stored in the Project File.

Table 8.1: Checklist for test pit logging (wearing course)

Parameter	Evaluation*					
	Severity	Extent	Start	End	Layer	Description and implications
Cracking						
• Transverse	✓	✓	✓	✓	✓	✓
• Longitudinal	✓	✓	✓	✓	✓	✓
• Fatigue	✓	✓	✓	✓	✓	✓
• Block	✓	✓	✓	✓	✓	✓
• Edge	✓	✓	✓	✓	✓	✓
• Reflective	✓	✓	✓	✓	✓	✓
• Corner	✓	✓	✓	✓	✓	✓
• Durability	✓	✓	✓	✓	✓	✓
• Map	-	✓	✓	✓	✓	✓
Rutting	-	✓	✓	✓	✓	✓
Shoving	-	✓	✓	✓	✓	✓
Ravelling	-	✓	-	-	-	✓
Scaling	-	✓	-	-	-	✓
Spalling	✓	✓	-	-	-	✓
Faulting	-	✓	-	-	-	✓
Joint seal damage	✓	✓	-	-	-	✓
Bleeding	-	✓	✓	✓	✓	✓
Pumping	-	✓	✓	✓	✓	✓
Polished aggregate	-	✓	-	-	-	✓
Aggregate condition	-	-	-	-	-	✓
Moisture condition	-	-	-	-	-	✓
Alkali-silica reaction	-	✓	✓	✓	-	✓
Corrosion	-	✓	-	-	-	✓
Pothole repair	-	✓	✓	✓	✓	✓
Crack repair	-	✓	✓	✓	✓	✓

Table 8.2: Severity and extent descriptors for wearing course layer assessment

Parameter	Rating	Rating description	Extent description
Transverse cracks	1 - Low 2 - Moderate 3 - High	Distress Identification Manual	Number, length (mm)
Longitudinal cracks	1 - Low 2 - Moderate 3 - High	Distress Identification Manual	Number, length (mm)
Fatigue cracks	1 - Low 2 - Moderate 3 - High	Distress Identification Manual	% area, depth (mm)
Block cracks	1 - Low 2 - Moderate 3 - High	Distress Identification Manual	% area, depth (mm)
Edge cracks	1 - Low 2 - Moderate 3 - High	Distress Identification Manual	Number, length (mm)
Reflective cracks	1 - Low 2 - Moderate 3 - High	Distress Identification Manual	Number, length (mm)
Corner breaks	1 - Low 2 - Moderate 3 - High	Distress Identification Manual	Number, depth (mm)
Durability cracks	1 - Low 2 - Moderate 3 - High	Distress Identification Manual	% area, depth (mm)
Map cracks	Severity not rated	-	% area, depth (mm)
Rutting	Severity not rated	-	Width, depth (mm)
Shoving	Severity not rated	-	% area, depth (mm)
Ravelling	Severity not rated	-	% area, depth (mm)
Scaling	Severity not rated	-	% area, depth (mm)
Spalling	1 - Low 2 - Moderate 3 - High	Distress Identification manual	Number, depth (mm)
Faulting	Severity not rated	-	Depth (mm)
Joint seal damage	1 - Low 2 - Moderate 3 - High	Distress identification Manual	Depth (mm)
Bleeding	Severity not rated	-	% area
Pumping	Severity not rated	-	Number, depth (mm)
Polished aggregate	Severity not rated	-	% area
Aggregate condition	Severity not rated	-	Description only
Moisture condition	Severity not rated	-	Description only
Alkali silica reaction	Severity not rated	-	% area
Corrosion	Severity not rated	-	Length (mm)
Pothole repair	Severity not rated	-	Description only
Crack repair	Severity not rated	-	Description only

Table 8.3: Checklist for test pit logging (bound layers)

Parameter	Evaluation*					Description and Implications
	Severity	Extent	Start	End	Layer	
Cracking						
• Horizontal	✓	✓	✓	✓	✓	✓
• Vertical	✓	✓	✓	✓	✓	✓
• Other	✓	✓	✓	✓	✓	✓
Rutting	-	✓	✓	✓	✓	✓
Pumping	-	✓	✓	✓	✓	✓
Erosion	-	✓	✓	✓	✓	✓
Fines intrusion	-	✓	✓	✓	✓	✓
Degradation	-	✓	✓	✓	✓	✓
Aggregate condition	-	-	-	-	-	✓
Moisture condition	-	-	-	-	-	✓
Mottling	-	✓	✓	✓	✓	✓
Frost action	-	✓	✓	✓	✓	✓
Layer definition	-	-	-	-	-	✓
Interlayer bond	-	-	-	-	-	✓
Moisture at interface	-	-	-	-	-	✓
Pothole repair	-	✓	✓	✓	✓	✓
Crack repair	-	✓	✓	✓	✓	✓
Bleeding ¹	-	✓	✓	✓	✓	✓
Carbonation ²	-	✓	✓	✓	✓	✓
¹ Asphalt treated base only			² Cement treated base only			

Table 8.4: Severity and extent descriptors for bound layer assessment

Parameter	Rating	Rating description	Extent description
Horizontal cracks	1 - Low 2 - Moderate 3 - High	≤ 6 mm 6 - 19 mm > 19 mm	Number, length (mm)
Vertical cracks	1 - Low 2 - Moderate 3 - High	≤ 6 mm 6 - 19 mm > 19 mm	Number, length (mm)
Other cracks	1 - Low 2 - Moderate 3 - High	≤ 6 mm 6 - 19 mm > 19 mm	Number, length (mm)
Rutting	Severity not rated	-	Width, depth (mm)
Pumping	Severity not rated	-	Number, depth (mm)
Erosion	Severity not rated	-	% area
Fines intrusion	Severity not rated	-	% area, depth (mm)
Degradation	Severity not rated	-	% area
Aggregate condition	Severity not rated	-	Description only
Moisture condition	Severity not rated	-	Description only
Mottling	Severity not rated	-	% area
Frost action	Severity not rated	-	Depth (mm)
Layer definition	Severity not rated	-	Description only
Interlayer bond	Severity not rated	-	Description only
Moisture at interface	Severity not rated	-	Description only
Pothole repair	Severity not rated	-	Description only
Crack repair	Severity not rated	-	Description only
Bleeding	Severity not rated	-	% area
Carbonation	Severity not rated	-	% area, depth (mm)

Table 8.5: Checklist for test pit logging (unbound layers)

Parameter	Evaluation*					
	Severity	Extent	Start	End	Layer	Description and Interpretation
Cracking						
• Horizontal	✓	✓	✓	✓	✓	✓
• Vertical	✓	✓	✓	✓	✓	✓
• Other	✓	✓	✓	✓	✓	✓
Rutting	-	✓	✓	✓	✓	✓
Pumping	-	✓	✓	✓	✓	✓
Erosion	-	✓	✓	✓	✓	✓
Fines intrusion	-	✓	✓	✓	✓	✓
Degradation	-	✓	✓	✓	✓	✓
Moisture condition	-	-	-	-	-	✓
Mottling	-	✓	✓	✓	✓	✓
Frost action	-	✓	✓	✓	✓	✓
Layer definition	-	-	-	-	-	✓
Interlayer bond	-	-	-	-	-	✓
Moisture at interface	-	-	-	-	-	✓
Pothole repair	-	✓	✓	✓	✓	✓
Crack repair	-	✓	✓	✓	✓	✓
Aggregate description	Described as per ASTM D 2488 - Description and identification of soils (visual-manual procedure)					
• Angularity						
• Shape						
• Color						
• Odor						
• HCl Reaction						
• Consistency						
• Cementation						
• Structure						
• Size range						
• Max particle size						
• Hardness						
• Condition						

Table 8.6: Severity and extent descriptors for unbound layer assessment

Parameter	Rating	Rating description	Extent description
Horizontal cracks	1 - Low 2 - Moderate 3 - High	≤ 6 mm 6 - 19 mm > 19 mm	Number, length (mm)
Vertical cracks	1 - Low 2 - Moderate 3 - High	≤ 6 mm 6 - 19 mm > 19 mm	Number, length (mm)
Other cracks	1 - Low 2 - Moderate 3 - High	≤ 6 mm 6 - 19 mm > 19 mm	Number, length (mm)
Rutting	Severity not rated	-	Width, depth (mm)
Pumping	Severity not rated	-	Number, depth (mm)
Erosion	Severity not rated	-	% area
Fines intrusion	Severity not rated	-	% area, depth (mm)
Degradation	Severity not rated	-	% area
Moisture condition	Severity not rated	-	Description only
Mottling	Severity not rated	-	% area
Frost action	Severity not rated	-	Depth (mm)
Layer definition	Severity not rated	-	Description only
Interlayer bond	Severity not rated	-	Description only
Moisture at interface	Severity not rated	-	Description only
Pothole repair	Severity not rated	-	Description only
Crack repair	Severity not rated	-	Description only
Aggregate description	Severity not rated	-	Description only

8.10. In-pit Testing

In pit testing will typically include, density, moisture content and dynamic cone penetrometer. Additional tests may be required to assess specific parameters (e.g. temperature gradient measurements on day of sampling). Care should be taken in interpreting measurements taken on the day of sampling, especially those that are weather related, given the wide variation that will be experienced between sites. When nuclear testing is carried out in a hole, it is useful to run a calibration check in the hole to check the influence of reflection – if large discrepancies are obtained compared with the standard counts, the results should be used with caution.

8.10.1 Reference Standards

The following reference standards are applicable to this Section:

- AASHTO T 310 - “In-place density and moisture content of soil and aggregate by nuclear methods (shallow depth)”

- ASTM D 2950 - “Standard test method for density of bituminous concrete in place by nuclear methods”
- ASTM D 5195 - “Test method for density of soil and rock in-place at depths below the surface by nuclear methods”
- ASTM D 6951 - “Standard test method for use of the DCP in shallow pavement applications”

8.10.2 In situ Density and Moisture Measurements

Pavement design procedures assume that the layers in the pavement structure have been compacted to specific minimum relative density and that the key structural parameters implied by meeting the specified density are reliable for design purposes and will vary little during the life of the pavement. Therefore the testing of the density is fundamental for assessing the validity of the designs. Key structural parameters such as strength, stability and modulus may change over time as a result of changes in moisture content, intrusion of fines, degradation and frost action and thus the assumption that a satisfactory relationship exists between relative density and the key structural parameters may not always be valid. In certain instances the specified density may not have been achieved during construction or may have been affected by mechanical action of traffic, frost or salt. By determining site specific conditions during the forensic investigation, the real relationships between the subsurface conditions and long-term performance will be better understood.

Equally important is the accurate determination of the in situ moisture content of each pavement layer, including the subgrade. Laboratory testing programs include a spectrum of tests, many of which are performed on representative samples compacted to the specified density at moisture contents simulating in situ conditions. Assessing the validity of these tests and the use of the results, along with parameters such as deflection, in pavement design will only be possible if accurate field density and moisture contents can be determined.

Three in situ density and moisture measurements should be made on the surface of all untreated base, subbase, and subgrade layers during excavation of the test pit. One measurement should be taken in each wheel path and one at the centre point between the wheel paths. One measurement (i.e. test) shall be the result of the average of four readings made during each 90° rotation of the nuclear gauge through a full 360°. Measurements should be recorded on an appropriate form (Form ? in Appendix C).

Special Provisions

Two nuclear gauges should be available at the test site. One gauge will serve as a stand-by in the event the regular test gauge becomes inoperative, or is of questionable accuracy. Nuclear equipment and testing will be conducted in full compliance with all federal, state, and local regulations. Nuclear gauge operators shall be licensed or qualified in accordance with requirements of appropriate agencies. Dosimeter badges should be provided to all field crew members involved in use of the nuclear gauges or working in close proximity. The badges should be periodically checked as required by Federal, state and local regulations.

Standardization of the nuclear density testing equipment on a reference standard is required at the start of each day's use and when the test measurements are suspect. Calibration of the nuclear gauges should be performed annually and at such other times that the accuracy of test results is questionable.

One density and one moisture measurement shall be made on each untreated base, subbase and subgrade soil layer, using the direct transmission method for density and backscatter method for moisture. For the density test the rod shall be imbedded 100 to 200 mm (4 to 8 inches) below the layer surface as appropriate to test the full layer. Each measurement shall be the average of four readings of one minute each taken at the same general location (hole) but with the instrument rotated 90° between each reading.

Prior to testing, the surface shall be leveled and smoothed and water, if present, in the test area shall be removed.

A bag and moisture jar sample shall be obtained beneath each test for laboratory moisture testing. Location for the test and obtainment of samples shall be as shown in Figure 8.?. Minimum sample sizes shall be 5 kg (± 11 pounds). The sample shall be dried to constant mass. Extreme care shall be taken to obtain samples at the true natural field moisture condition. The density, moisture, type of material, rod end depth and thickness of the each tested layer shall be reported on the form. Any unusual findings during the testing and bulk sampling such as voids, oversize aggregate or cobbles, foreign material, trapped water, etc. which may have affected the measurements should also be reported. Tests are not required on subgrade material containing an amount of rock sufficient to preclude accurate testing.

8.10.3 Dynamic Cone Penetrometer (DCP) Testing

The DCP test provides a simple and inexpensive means of determining layer strengths at a particular point on the road at a particular time. Although comprehensive deflection (FWD) measurements might have been recorded on each section throughout the study, the FWD equipment is not always available for regular routine testing of other pavements. The taking

of DCP measurements on the experiment will provide an opportunity to compare measurements with the deflection measurements already taken.

If DCP measurements are considered necessary, they should be taken prior to excavation of the test pits in each of the wheel paths and in-between the wheel paths. Measurements should be recorded at 5-blow intervals to a depth of 800 mm (± 320 inches). If layers are particularly weak, measurements should be taken after every blow. Bound layers should be drilled.

Results should be recorded on the DCP Form (Form ? in Appendix C).

8.10.4 Other Testing

Depending on the type of experiment and the type and nature of the distress recorded, additional on site testing may be required. The details of any other testing carried out should be noted on the assessment form. The data collected should be recorded on an appropriate form and attached to the Forensic Study Site Report.

8.11. Test Pit Reinstatement

Following completion of the test pit activities, the pit should be reinstated.

8.11.1 Asphalt Concrete Pavements

Excess untreated material should be replaced in the pit and compacted in layers corresponding to the original pavement structure at the correct moisture content and similar density to the adjacent materials. Base and surfacing should be reinstated in the form of a patch using asphalt concrete according to state specifications. Quality control should be carried out according to state requirements. The patch should be monitored after reinstatement to ensure that settling has not occurred and that there is no cracking or possibility of water ingress at the joints.

Core holes should be patched with an appropriate mix according to state requirements.

8.11.2 Portland Cement Concrete Pavements

The following procedure should be followed when opening the test pit in order that the slab can be replaced on completion of the investigation:

- Saw completely through concrete surface along all edges of the test pit and place anchor plugs in the pavement slab to be removed
- Place anchor bolts in the plugs and string steel cable through the eyelets
- With backhoe or front end loader attached to the cable, lift the test pit slab in one piece and place beside the test pit area
- Complete all sampling and testing activities as described in the previous chapters
- Replace sampled areas with suitable base and subbase material and compact with pneumatic tampers to maximum attainable density to a level even with the bottom of the concrete surface. The density should be measured and recorded as described previously.
- Replace the concrete slab, remove anchor bolts, and seal joints as per the appropriate state specifications

For continuously reinforced concrete or other instances when the above procedure is not feasible, an overnight lane closure followed by permanent patching the following day or the placement of a temporary patch at the completion of the sampling and testing followed by permanent restoration at a later time may be employed.

If temporary patching is elected, the following procedure can be considered:

- After completion of the testing, place aggregate base material equivalent to that removed
- Compact each layer with pneumatic tampers to maximum attainable density. The density should be measured and recorded as described previously.
- Place asphalt concrete temporary patch mixture (hot mix or cold mix of high stability) in two layers and compact each layer with pneumatic tampers to maximum attainable density.
- This temporary patch should be replaced by a more permanent restoration of the pavement surface at a more suitable time.

8.11.3 Site Cleanup

The responsible official should remove all signs, equipment, material and debris from the work site. This shall include, but not be limited to, loose soil, particles of aggregate, concrete, asphalt, and mud coatings on the roadway and shoulder. Material removed from the test pit that is not required to be shipped or used to restore the test pit shall be disposed of off the State Right-of-Way and in accordance with state highway and local legal requirements.

8.12. Project Site Report

The project site report should only be signed off when the Project Engineer is satisfied that all materials have been shipped, that the pit and core holes have been correctly reinstated, markings repainted and that the site has been satisfactorily cleaned up

8.13. Checklists

All relevant issues will be listed on the forensic investigation checklist, which must be signed off by the Project Engineer(s) on completion of construction. Examples of the checklists relevant to this chapter are provided in Appendix B.

8.14. Quality Management

Quality management issues pertaining to the roles and responsibilities described in this Chapter include:

- Understanding the requirements for a forensic investigation in the Experiment Specification or motivating the need for one if the matter was not considered earlier
- Undertaking the forensic investigation according to standard practices
- Sampling all relevant materials at the time and to the requirements specified in the Experiment Specification
- Completing all relevant checklists, forms and labels

8.14.1 Data Management

Considerable data will be collected during a forensic investigation. Data should be recorded on appropriate forms designed to meet the needs of the experiment. Examples of forms are provided in Appendix C. Mandatory information should include:

- Name of evaluator
- Date
- Road number
- County/district
- Section name and number
- Signature of evaluator

- Signature of person performing quality management

All documents should be added to the Project File. In order to facilitate later data analysis, all data from the forms should be captured into a spreadsheet as soon as possible after the forensic investigation (ie one week). Timeous capture will allow checks to be made and any missing data to be collected while the investigation is still clear in the Engineers mind. A copy of the spreadsheet, named according to the experiment naming principle described earlier, plus date, should be forwarded to the Database Manager.

8.14.2 Responsibility

The Project Engineer is responsible for:

- Undertaking or delegating the forensic investigation as detailed in the Experiment Specification
- Ensuring that the forms and other relevant documentation are sent to the Database Manager
- Ensuring that any samples collected reach the laboratory and are tested as per the Experiment Specification

The Database Manager is responsible for:

- Capturing the data in the database
- Maintaining the Project File

The Project Director is responsible for:

- Deciding whether a forensic investigation is justified
- Approving all checklists

9. LABORATORY TESTING

9.1. Introduction

Laboratory testing is carried out in order to obtain an understanding of the material characteristics of the existing road surface or treatment being applied. In most instances these properties need to be known in order to understand why the road performed the way it did and to determine a set of criteria that can be used as a basis for determining where treatments or techniques that are being assessed can be applied elsewhere on the network.

Laboratory testing should only be carried out when the results will enhance knowledge of how the pavement performed and the reliability of the findings of the study in terms of addressing the study objectives. Testing should not be carried out simply for the sake of testing. The need for testing and the type of testing will be identified in the Experimental Specification.

Testing that might be carried out includes, but is not limited to the following. In all instances, control specimens should also be tested for comparative purposes.

- Binders and rejuvenating sprays
- Aggregate
- Fillers
- Crack and joint sealants
- Reinforcing grids
- Cores and slabs

9.2. Tests

A discussion on laboratory testing falls outside the scope of the document. However, the following should be considered before testing:

- Care should be taken to fully understand a test, its purpose and its limitations before selecting it. Most tests are developed for a specific purpose. When used to test something outside the original scope, the mechanism and results may not be entirely relevant. Results need to be interpreted with care and the test may need to be modified to suit the need.

- An appropriate method may need to be sought to test a particular parameter. This may not be commonly used within Caltrans and laboratory staff may need to be trained in its use. Alternatively, a new test may need to be developed to address a particular need.
- Test methods should be strictly adhered to, unless modified to suit the needs of the experiment. If modified, the changes need to be clearly documented with a justification for doing so. Test methods should not be changed simply to obtain a satisfactory answer.

Laboratory testing procedures are fully documented in *Caltrans specific*. Test methods for most materials are also documented in ASTM test methods.

10. DATA ANALYSIS AND REPORTS

10.1. Introduction

Appropriate data analysis and reporting is a fundamental part of any experiment. In this phase of the research, the data collected from the visual assessments and measurements is analysed to determine whether the treatment, technology, procedure and/or product performed and behaved in a manner, such that adoption of it would have benefits over existing practice. These benefits could include, but are not limited to:

- Improved performance
- Longer periods between maintenance treatments
- Reduced user delays
- More cost-effective
- Easier to construct

In this chapter, data analysis, progress, and first and second level analysis reports are discussed.

10.2. Data Analysis

The focus of data analysis will be the systematic comparison of the behaviour and performance of the treatment, technology, procedure or product against that of the control. The criteria that are used for this comparison will depend on the Experiment Specification. Examples include, but are not limited to:

- Cost
- Time taken to 'fail' (eg riding quality, rutting, cracking, etc)
- Mode of failure
- Maintenance requirements
- User delays associated with construction

10.3. First Level Analysis Report

A first-level analysis report should be compiled when all testing has been completed (ie experiment termination point has been reached) and all data has been captured. It should provide a background to the study, the study objectives, experimental design, monitoring, measurements taken, interpretation and recommendations for and benefits/implications of adoption. The report should be prepared by the Project Engineer in Caltrans Research Report format, reviewed by a Technical Specialist and approved by the Project Director before being submitted to the relevant Caltrans Departments. The content of the report will be detailed in the Test Specification, but will typically include the following chapters:

- Introduction
- Project team
- Test specification and revisions
- Site selection and location
- Construction
- Evaluation
- Benefits and implications of adopting the technology
- Conclusions and recommendations
- References
- Appendices

10.4. Second Level Analysis Report

A second level analysis report should be prepared if the experiment was part of a larger study. This report should summarize the entire study, detail the benefits and implications of adopting the technology and provide recommendations for implementation. The actual content of the report will depend on the objectives of the experiment. The report should be prepared by the Project Engineer(s). The standard Caltrans Report format and approval procedures should be followed. The report should be reviewed by a Technical Specialist and approved by the Project Director before submission to the relevant Caltrans Departments.

11. DATA MANAGEMENT AND DOCUMENTATION

11.1. Introduction

A comprehensive record of the behaviour of the test section and comparison to a control is critical to the success of any experiment. This requires a systematic data capture and storage procedure to ensure accuracy, uniformity and continuity in measurements.

The Project File, checklists, data collection forms, proposal register, experiment register and progress reports are discussed in this chapter.

11.2. Project File

A project file should be opened for each experiment when a proposal is prepared. The project file will need to accommodate both electronic and paper based data. All documentation associated with the experiment should then be filed in the Project File for future reference. Initially, the project file will be the responsibility of the person preparing the proposal, but once the proposal is approved/rejected, it will become the responsibility of the Database Manager. It should be remembered that the Project File “belongs” to an experiment and not to an individual and the contents should be accessible to any interested person.

Contents of the project file should include, but not be limited to:

- Proposal
- Records of decision
- Experiment specification (all versions)
- Experiment location, details and map
- Construction report
- Monitoring forms and photographs
- Progress reports
- Analysis documentation
- First and second level analysis reports
- Recommendations for implementation
- Experiment termination report

11.3. Checklists

Checklists are an effective way of ensuring that all relevant tasks for a particular part of a study are completed. They also provide a record to prove that the tasks were carried out and can also be used to guide the process.

Examples of checklists are provided in Appendix B. Depending on the type of experiment and the data requirements, experiment specific forms may need to be prepared. It is important that the form used remains constant throughout the evaluation to facilitate comparison during data analysis.

Checklists should be signed off by the responsible individuals on completion of a task.

11.4. Data Collection Forms

Data collection forms will be the primary source of information in most experiments. They should be filled in with care and as comprehensively as possible, remembering that data analysis may be carried out by someone other than the individual who did the assessment, and may be carried out a number of years later when recollection of the assessment may be difficult.

Standard Data Collection Forms are provided in Appendix C. Depending on the type of experiment and the data requirements, experiment specific forms may need to be prepared. It is important that the form used remains constant throughout the evaluation to facilitate comparison during data analysis.

Wherever appropriate, explanatory notes should be added to the evaluation form to better describe attributes of the experiment and the contents of photographs. The evaluator should always bear in mind that data analysis will be undertaken at a much later date and clarity in the information and explanation with the ratings will assist in the analysis, the drawing of conclusions and with recommendations for implementing the procedure or product.

Photographs and videos will be invaluable in later analysis. Cross references and details when the photograph and videos were taken and what they illustrate must be captured on the evaluation form.

All data from the forms should be captured into a spreadsheet as soon as possible after they have been collected. In certain instances, data may be captured directly into a spreadsheet on site during monitoring, however, in most instances, the nature of the monitoring exercise renders in unsuitable for direct data capture. Timeous capture will allow checks to be made and any missing data to be collected while the construction process is still fresh in the Engineers mind (typically five days). A spreadsheet should be created for each section within the experiment. Separate worksheets should be created within the spreadsheet for each assessment and named according to date of the assessment. The format of each worksheet should be exactly the throughout to facilitate statistical analyses. The spreadsheet should be named according the experiment and section number together with date.

By capturing data on separate sheets with the same format, first-level data checks can be carried out using comparative graphs.

11.5. Proposal Register

Caltrans specific

11.6. Experiment Register

Caltrans specific

11.7. Progress Reports

Progress reports provide a means for maintaining momentum with the experiment and for informing individuals not directly involved in the study about progress. They should be brief to ensure that they are read. They should follow a standard format to ensure that only relevant information is included. Content should include:

- Evaluations completed since previous report

- Performance compared to that detailed in the previous report
- Implications
- Recommendations to continue or terminate the experiment

Progress reports are typically prepared once or twice a year and should coincide with monitoring evaluations.

Progress reports are prepared by the Project Engineer and approved by the Project Director.

11.8. Data Validation and Storage

The data collected from each evaluation should undergo a first-level data check by both the Project Engineer and the Database Manager. This will include, but not be limited to:

- A check that data does not fall outside predetermined minimum and maximum boundaries (eg a severity cannot exceed 5, percentage areas cannot exceed 100)
- A comparison with data collected from the previous monitoring exercise to check inconsistencies (eg rut depth less than previous)

Data can be transferred from the forms to a spreadsheet to facilitate later analysis. However, the original forms must be retained in the project file for later reference. Photographs should be stored electronically in a series of subdirectories linked to the monitoring dates. Care must be taken to ensure that the numbers on the photographs match those on the evaluation forms and that there will be no confusion when analysing the data. Electronically collected data should be stored in a similar manner.

The quantity of data typically collected from a maintenance treatment test section, combined with the rapid developments in the Information Technology arena, necessitate conscientious and regular attention to the entire database to ensure that it is always accessible using current hardware and software. Considerable useful information on various road projects collected in the past has been lost or become unusable due to poor or erratic database management. The database must be comprehensively backed up regularly and these backups must always be upgraded when new hardware and software is installed.

The database should be compatible with other relevant databases in order that results can be directly compared or analysed together.

In order to facilitate the use of the information in the databases by authorised individuals, Internet access should be considered as part of the database development.

11.9. Report Numbering

Caltrans specific

12. REFERENCES

- 1.
- 2.
- 3.

APPENDIX A

EXAMPLE EXPERIMENT SPECIFICATION

APPENDIX A: EXAMPLE EXPERIMENT SPECIFICATION

A.1 ??

APPENDIX B

CHECKLISTS

APPENDIX B: CHECKLISTS

Examples of the following checklists typically used in Maintenance Treatment experiments are provided in this Appendix:

- ?

APPENDIX C

EVALUATION FORMS

APPENDIX C: EVALUATION FORMS

Examples of the following forms typically used for the monitoring of Maintenance Treatment experiments are provided in this Appendix:

- Visual assessment, profile and deformation
- Data acquisition (electronic)
- Back-up data collection
- Density and moisture content
- Daily service
- HVS operations
- Test pit
- DCP
- Client weekly report

The following calibration forms are also provided:

- Road surface deflectometer
- Multi-depth deflectometer

